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January 2018

ESSENTIALS FOR THE CPI PROFESSIONAL

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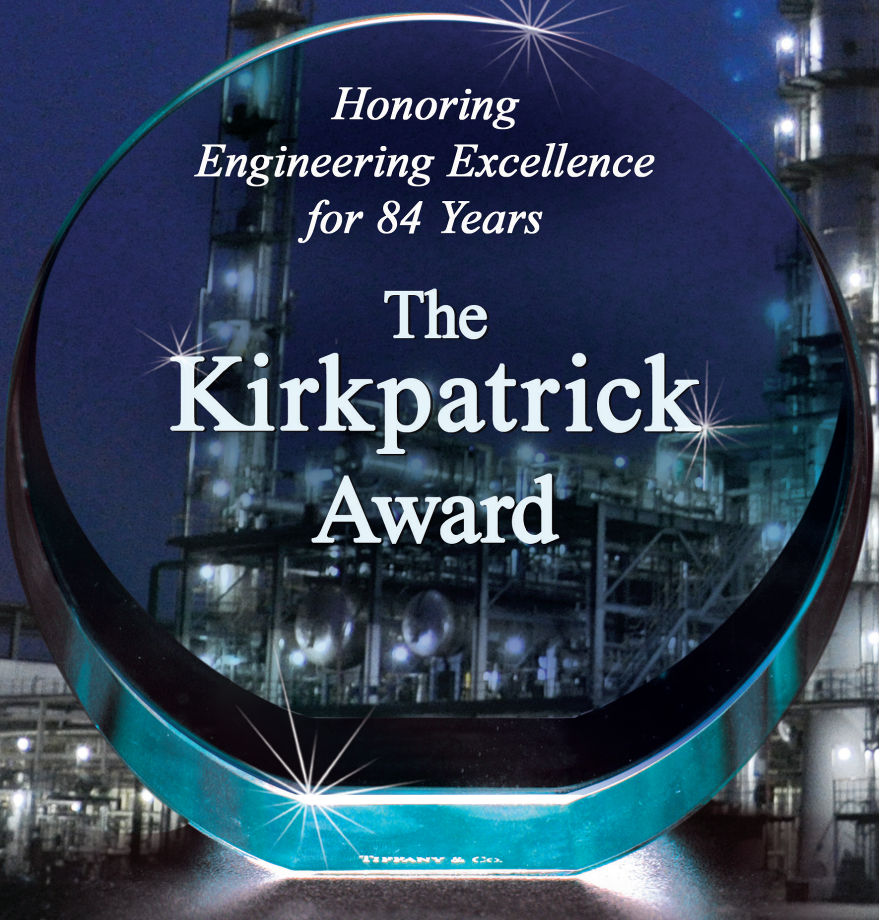
Process Commercialization

page 22



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January 2018 Volume 125 | no. 1

Cover Story

In the News

Technical and Practical


22


11


46

56

15

18

Equipment and Services

Departments

Advertisers

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CHEMICAL ENGINEERING
ESSENTIALS FOR THE CPI PROFESSIONAL

Editor's Page

Starting strong

Last month, the American Chemistry Council (ACC; www.americanchemistry.com) issued its annual year-end report, which offers a positive outlook for the chemical process industries (CPI). The report, "Year-End 2017 Chemical Industry Situation and Outlook," was prepared by the ACC's Economics and Statistics Department, with the ACC's chief economist, Kevin Swift, as lead author. According to Swift, "Manufacturing has turned a corner, business investment is on the rise, and domestic oil and gas production is on the rebound. It all sets the stage for tremendous momentum, expansion, and capital investment."

Industry outlook

In the U.S., the abundant and inexpensive feedstock and energy advantages offered by shale gas developments have led to significant capital investments, and continue to play a prominent role in the direction the CPI are taking. More than half of the investments announced since 2010 are either under construction or have been completed.

The report estimates that chemical production volumes (excluding pharmaceuticals) were up 0.8% in 2017 despite interruptions to production in the Gulf Coast region due to the severe hurricanes experienced in August. Production volumes are poised to go up more in the near future — by 3.7% in 2018. "In addition," the report says, "a second wave of investment is on the way." And, the oil-and-gas sector, which had been in a slump, is said to be on the rebound. Most of the CPI growth in the U.S. is expected to be in the Gulf Coast region, the Ohio Valley and the Southeast. Increased production would generate materials for export, so any changes in trade policy, however, could have a strong effect on projected growth.

On a global view, the report cites a strengthening in manufacturing, and in fact says, "Outside the United States, a synchronized upswing among major and regional economies is occurring for the first time since the mid-2000s."

In this issue

The overall optimistic message of the year-end report gives the CPI a strong starting point for 2018. The challenges, however, are many — particularly in keeping up with growing competition. Companies are looking to innovative process and product improvements, as well as implementing new developments, such as in digitalization, to maintain a competitive edge. Our two-part Cover Story this month (pp. 22–32) takes a close look at a select group of innovative processes that have been developed, and commercialized in the past two years. The road to commercializing a new process can be long and difficult, and so, in addition to covering the impressive process and product developments, we compiled some of the best practices for commercialization that were used in these accomplishments.

You will also find articles on pumps, pressure measurement, career guidelines for young engineers, high-shear mixing and more in this issue. We look forward to bringing you the variety of topics that we have planned for this year. We hope you find the articles informative, and as always, we welcome your feedback.

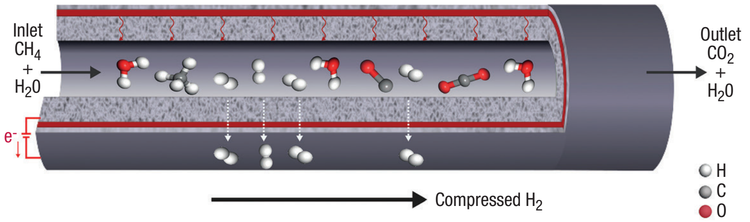
Our best wishes to all of our readers for a happy, healthy and prosperous new year. ■

Dorothy Lozowski, Editorial Director

Ceramic-membrane technology simplifies steam methane reforming

Edited by:
Gerald Ondrey

CoorsTek Membrane Science



A new type of steam-reforming system that produces — in a single step — purified, compressed hydrogen from methane has been developed by a team of scientists from CoorsTek Membrane Sciences AS (Oslo; www.coorstek.com), the University of Oslo (both Norway; www.uio.no) and the Institute of Chemical Technology (Valencia, Spain; http://itq.upv-csic.es). In a laboratory-scale system, the so-called protonic membrane reformer (PMR) has been shown to achieve complete conversion of CH_4 into two separate streams: wet CO_2 and H_2 with impurity levels of less than 4 parts per million (ppm) — clean enough for fuel-cell operation. The system has an overall energy efficiency of more than 87%.

As described in a recent issue of *Nature Energy*, the PMR is a tubular electrochemical cell with a proton-conducting electrolyte (BZCY: $BaZr_{0.8\text{-}x\text{-}y}Ce_xY_yO_{3\text{-}\delta}$) sandwiched between two porous electrodes of BZCY and Ni. Methane and steam pass through the center of the reformer tube at a temperature of 700–850°C and a pressure of 5–30 bars. By applying a voltage across the electrolyte, H_2 is selectively extracted from the inner reforming chamber by migrating through the proton-conducting membrane to generate pure H_2 on the other side of the membrane. The H_2 separation also serves to drive the thermodynamically limited reaction to full methane conversion. At the same time, the heat required for the highly endothermic reforming and water-shift reactions is supplied by the electrical operation of the membrane. The added bonus is that the product H_2 is also compressed (electrochemically) to a pressure of 50 bars. In contrast, alternative membrane-reactor systems, such as those based on palladium membranes, are driven by partial pressure differences across the membrane, and thus require additional multistage compressors, with the associated capital and operating costs, to produce compressed H_2.

CoorsTek Membrane Sciences believes such ceramic membrane systems can be a cost-competitive technology for H_2 production with integrated CO_2 capture, even at a scale required for cost-effective ammonia production. The company says it has the manufacturing capabilities to make ceramic membranes cost competitive with traditional energy conversion technology for both industrial- and small-scale H_2 production. "A prototype membrane-manufacturing line is already operational, and an H_2 mini-plant is now under construction with capacity to make up to 5 kg/d of H_2," says CoorsTek managing director Per Vestre.

3-D PRINTING

At the 3-D printing tradeshow Formnext in November, GE Additive (Paris, France; www.ge.com) unveiled a laser-powder additive manufacturing machine with a 1-m^3 build envelope. The machine, said to be the world's largest laser-powder system, will be used to make structural components for jet engines in the aerospace industry, as well as parts for the power, oil-and-gas and automotive industries. GE says the build geometry of the machine will be customizable and scalable for each project, and its feature resolution and build-rate speeds will equal or exceed current additive machines. GE also says the machine, known as Atlas, is designed to be used with multiple materials, including non-reactive and reactive materials (such as aluminum and titanium).

'DIGITAL FERTILIZER'

Toyo Engineering Corp. (Toyo; Chiba, Japan; www.toyo-eng.co.jp) has developed and launched the first commercial application of its "Digital Fertilizer" technology — an internet of things (IoT)

(Continues on p. 6)

Microbe-impregnated matrices reduce biosolids in wastewater

High-surface-area beads filled with microbes are being used to eliminate pollutants in wastewaters. In one case, Drylet LLC (San Francisco, Calif.; www.drylet.com) has developed engineered porous particles that provide large surface areas (the equivalent of 12 football fields of surface area per pound of material).

Using a proprietary process, the chemically inert particles are loaded with microbes that consume biosolids (sludge) in wastewater applications. The large surface area allows for the remarkably large microbe concentration of 1×10^{11} colony-forming units (cfu) per gram, or about 100 times the concentration of liquid products.

The non-genetically modified microbes convert solid sludge mass into gases and water, reducing sludge volumes by up to 50% with no capital investment, according to the company.

"We are looking to reprogram the microbial communities at wastewater treatment plants to promote the microbial activity of beneficial microbes and help them outcompete those that are less useful," explains Luka Erceg, president and CEO of Drylet.

Microbes within the porous network are protected from attack by other bacteria and protists in the water and can grow quickly. In addition, the process of introducing the microbes to the solid-bead matrix and the method of use for sludge treatment ensures that first-generation microbes are added each day, Erceg says. These are more active than "older" microbes, he says.

The reduction of biosolids lowers disposal costs, and decreases maintenance requirements and electrical costs, Erceg says. He adds that the impact of the product on reduced ammonia emissions also leads to lower chemical bleach usage. (For a related sludge-reducing technology, see p. 25).

system that contributes to improving operating rates and plant profitability by continuously monitoring and analyzing plant operations and key performance indicators (KPIs) of the plant. The system has been applied in a 2,750-ton/d urea plant owned and operated by PT Pupuk Sriwidjaja Palembang in Palembang in South Sumatra, Indonesia as a subsidiary of the state-owned Indonesian fertilizer company, PT Pupuk Indonesia.

In December 2016, Toyo and General Electric Co. (GE; Boston, Mass.; www.ge.com) signed a memorandum of understanding (MoU) for a joint project to explore digital solutions for the fertilizer and petrochemicals industries. Under the MoU, Toyo and GE jointly developed Digital Fertilizer on GE Predix, which is a unique cloud-based platform built exclusively for industry by using Toyo's expertise in processes and plant operations as licensor of urea synthesis and granulation technologies and as engineering procurement and construction (EPC) contractor of fertilizer and petrochemical plants. System integration of Digital Fertilizer on Predix was conducted by NEC Corp. (NEC; Tokyo; www.nec.com), which has entered into a comprehensive alliance with GE.

FLUOR PILOT PLANT

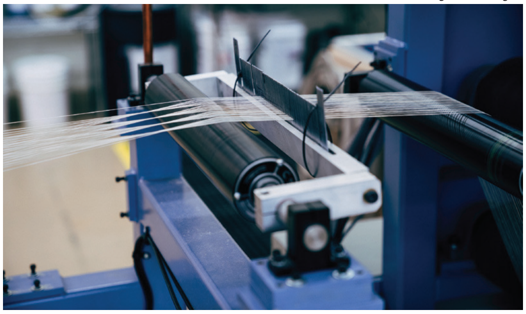
The newly-named Fluor Pilot Plant is now being used by chemical engineering students at the University of Surrey's Department of Chemical and Process Engineering (Guilford, U.K.; www.surrey.ac.uk). A donation of $300,000, made through Fluor's philanthropic organization, the Fluor Foundation, was provided to the university earlier this year to upgrade and refurbish the plant to produce industry-prepared engineers.

The Fluor Pilot Plant also provides realistic industry experience to trainee chemical weapons inspec-

(Continues on p. 7)

Foam-dyeing process cuts water and chemicals in denim production

Indigo Mill Designs



Foam dyeing, a new technology for dyeing cotton yarn that is being applied to denim production for the first time, eliminates the use of several chemicals and can reduce water use by up to 90% compared to traditional dyeing. The foam-dyeing process, known as IndigoZERO, was developed at the Fiber and Biopolymer Research Institute at Texas Tech University (Lubbock; www.texastech.edu) and is being commercialized by Indigo Mill Designs LLC (IMD; Greensboro, N.C.; www.indigomilldesigns.com).

Traditional dyeing of denim involves dye baths, in which the indigo dye is treated with a reducing agent (sodium hydrosulfite) and pH-adjusting sodium hydroxide to render it soluble in water. The cotton yarns used for making denim are dipped continuously as ropes into the baths, and then removed and exposed to air in a step called skying to oxidize the indigo back into its raw form to color the yarn. Making denim typically requires six or more dip-and-skye cycles and several rinses, all of which require substantial amounts water, which then must be treated.

The foam-dyeing process, on the other hand, uses surfactants to generate an aqueous dye-containing foam, which is then pushed into intimate contact with cotton yarn in an oxygen-free chamber. The dye is converted back to indigo in a subsequent oxidation chamber to dye the cotton blue. The Texas Tech/IMD process has allowed foam dyeing to be used to color yarn with indigo, opening its use in denim production. Previously it could only be used on already woven fabric.

The new process has a host of environmental benefits without adding cost. Traditional denim production requires 400 gal of water for each 100 yards of fabric, also with 370 lb of NaOH and 39 lb of reducing agent for 100 lb of raw indigo dye, explains Sudhakar Puvvada, an advisor to IMD and the leader of the denim global innovation center for Wrangler and Lee brands, which have invested in the technology. Foam-dyeing eliminates the need for NaOH and sodium hydrosulfite, and reduces the water requirements to 3.5 gal per 100 yards of fabric, he says. Electricity consumption and physical footprint of the dyeing operation are both reduced substantially as well, Puvvada adds.

A step closer for graphene-coated anodes

A new collaboration between PPG (Pittsburgh, Pa.; www.ppg.com), SiNode Systems (Chicago, Ill.; www.sinodesystems.com) and Raymor Industries (Boirsbriand, Que., Canada; www.raymor.com) aims to accelerate commercialization for battery anodes made of a silicon-graphene composite. "These materials can achieve significantly higher capacities than current graphite-based anodes, allowing for higher cell-level energy density," explains Kurt Olson, PPG corporate research fellow. In electric-vehicle batteries, these traits lead to lighter-weight batteries and increase the distance vehicles can travel on a single charge. "Traditionally, the addition of silicon causes a decrease in a battery's cycle life because the silicon expands during charging and breaks into tiny particles that are no longer effective," says Olson. Coating silicon particles with a layer of graphene effectively increases the life of batteries.

SiNode produces few-layer graphene nanoplatelets from methane via an atom-by-atom, "bottom-up" plasma process. The plasma's high temperature breaks the methane into carbon atoms and hydrogen, and in a specially designed reactor, the carbon atoms are combined into graphene as they cool. "This continuous manufacturing process from a low-cost carbon source results in consistent-quality graphene," says Olson.

According to the research team, graphene produced in this manner possesses composition, morphology and uniformity that make it better suited to improve anode performance when compared to other graphene sources. Graphene produced via traditional "top-down" batch processes require several liquid dispersion steps, as well as purification, resulting in more waste and product variability when compared to the single-step approach. Olson expects the plasma-based process to be quite cost-competitive as production volumes increase.

In order to lower battery costs and increase the cycle life of batteries containing the silicon-graphene electrodes, the team is simultaneously working to scale up the graphene production process, optimize the particle-coating process and develop stable dispersion technologies that are tailored for the anode composition.

Waste coffee grounds are used to make biodiesel blend

A biodiesel fuel blend known as B20 contains oils derived from waste coffee grounds, and will be used to power mass transit buses in London. The fuel is made through a partnership among bio-bean ltd. (London, U.K.; www.bio-bean.com), which has developed a process for extracting useful oils from waste grounds, biodiesel producer Argent Energy and Royal Dutch Shell.

The B20 biofuel is made by combining oil from the waste coffee grounds with other recycled waste fats and oils, and blending that with mineral diesel fuel. Because recycled waste oils, including the coffee oil, makes up 20% of the B20 biofuel, it is 85% more carbon efficient than standard diesel and achieves a 10–15% CO_2 reduction over standard diesel.

Bio-bean works with waste management partners to collect waste coffee grounds from coffee chains, independent coffee shops, transport hubs, office blocks and instant coffee factories. The grounds are dried and processed at bio-bean's Alconbury factory, before a specialized solid-liquid extraction process is used to isolate the oils from the waste grounds. The solvent is fully recovered and recycled, bio-bean says.

Argent Energy blends this coffee oil with other biologically derived fats and oils and then combines this mixture with mineral diesel to create a B20 blended biofuel. The fuel is then supplied directly into the London bus network. With Shell's help, bio-bean and Argent Energy have produced 6,000 L of pure coffee oil, enough to produce 30,000 L of B20 biofuel.

A photocatalyst for reducing CO_2 to CH_4

Photocatalytic reduction of CO_2 into a fuel is an attractive way to reduce CO_2 emissions into the atmosphere, and there are many projects underway around the world to find ways of converting CO_2 into chemicals, such as H_2, CH_4, ethanol, methanol and butanol. However, in order to utilize CO_2 as a resource, it is essential to improve the light-absorption efficiency and the CO_2-conversion efficiency, and to ensure that the photocatalyst helps prevent the production of secondary harmful substances. Although a number of active photocatalysts have been reported, they suffer from low product yield, instability and low quantum efficiency.

Now a team from the Daegu Gyeongbuk Institute of Science and Technology (DGIST, Daegu, South Korea; https://en.dgist.ac.kr), led by professor Su-Il In, has succeeded in developing a TiO_2-based high-efficiency photocatalyst that converts CO_2 to CH_4 by means of a simple reduction reaction. The catalyst is made by treating TiO_2 with a strong reducing agent — sodium borohydride ($NaBH_4$) — at 350°C for half an hour.

Sensitized with Pt nanoparticles, the material promotes solar spectrum photoconversion of CO_2 to CH_4 with an apparent quantum yield of 12.40% and a time-normalized CH_4-generation rate of 80.35 μmol/g·h. Professor In says to the best of his knowledge this is a record for photocatalytic-based CO_2 reduction. He plans to further improve the CO_2-conversion efficiency with a view to commercialization.

tors who use the facility to gain practical hands-on experience in preparation for their field work. The trainees are from the Nobel Peace Prize-winning Organization for the Prohibition of Chemical Weapons (The Hague, the Netherlands).

FLOWER POWER

Researchers at Karlsruhe Institute of Technology (KIT; Germany; www.kit.edu) have discovered that the texture of the viola petal (*Viola wittrockiana*) drastically reduces reflection losses. In nature, this effect leads to a bright and saturated color impression, which the flowers use to attract possible pollinators, says KIT. The researchers have demonstrated a 6% relative improved performance of a silicon solar cell by mimicking the viola as front-side texture. The results are described in *ACS Photonics*.

Analysis of the surface texture of the viola flower reveals that it exhibits a hierarchical texture consisting of cones (on the order of tens of micrometers) and nanoscopic wrinkles adorned on top of the cones. This hierarchical texture is able to efficiently increase light incoupling when used as coating on top of solar cells. In addition, it reduces the loss of light at the interface between the encapsulation and the solar cell, by redirecting escaping light. According to the scien-

(Continues on p. 8)

Making ethylene by artificial photosynthesis

A team from the National University of Singapore (www.nus.edu.sg) led by professor Boon Siang Yeo has developed a prototype device that mimics natural photosynthesis to produce ethylene using only sunlight, water and CO_2, at room temperature and pressure.

The team designed a two-electrode cell and optimized cell parameters such as electrolyte and voltage. A photovoltaic cell is first used to convert solar energy to electricity, and the electricity powers the electrolyzer to produce substances from CO_2 to H_2O. The team used oxide-derived copper as electrocatalyst in the cathode and iridium oxide as electrocatalyst in the anode. Coupling the cell with silicon solar panels under sunlight (100 mW/cm^2), the team showed that CO_2 could be easily reduced to ethylene with an efficiency of 31.9%, when operating the system with a partial current density of 6.5 mA/cm^2. Under these conditions, the overall photosynthetic efficiency (solar-to-ethylene) was 1.5%, but this could be increased to 2.9% by the addition of ethanol and *n*-propanol to the system. The introduction of insoluble chelating agents in the electrolyte improved the longevity of the cell, by capturing contaminants, such as dissolved iridium ions.

A prototype system incorporates a battery, which stores excess solar energy, thereby enabling the stable, continuous production of ethylene. The team believes its work has helped solve many problems associated with the implementation of an artificial photosynthesis system and represents a major step forward in the field of solar energy utilization.

tists, an application of the new findings is not limited to silicon solar cells, but also applicable to other technologies, where reflection losses occur.

DIRECT FtoC MOLDING

Adeka Corp. (www.adeka.co.jp) and GH Craft Ltd., the composite structure design, development and evaluation business unit of Teijin Group (both Tokyo, Japan; www.teijin.com), have jointly developed the world's first fiber-to-composite (FtoC) molding process to laminate fiber-reinforced plastics (FRP) in open molds. The FtoC molding process automates resin impregnating, curing and laminating processes while aligning highly oriented fibers. A new, rapid-curing epoxy resin developed by Adeka enables FRP to be cured in just tens of seconds with GH Craft's new molding process using infrared radiation. Large-scale equipment, such as curing ovens and press molds, are not needed because the FRP can be laminated in an open mold.

By extending and highly orienting fibers, the process produces glass-fiber-reinforced plastics (GFRP) that offer significantly improved performance, including 100% more bending strength, 40% more tensile strength and 75% more interlayer shear strength compared to conventional GRFP made with conventional resin-transfer molding, says Teijin.

MOLTEN Na MAKES NH_3

Fumio Kawamura and coworkers at the National Institute for Materials Science (NIMS; Tsukuba City,Japan; www.nims.go.jp/high-pressure) have discovered that molten sodium can be used as a new catalyst for making ammonia. The scientists simply bubble a mixture of 4 vol.% H_2 and 96 vol.% N_2 at atmospheric pressure through molten sodium at 500–590°C in a quartz reactor tube. Under these conditions, N_2 molecules dissociate and react with H_2 to form NH_3. However, because the yield is only 0.1% so far, it will be a while before the technology replaces the century old, energy-intensive Haber-Bosch process.❑

Enhancing the stability of perovskite solar cells

Perovskite solar cells have attracted much interest in the past few years as the next-generation solar cells capable of surpassing silicon cells' efficiency. However, because the perovskite materials are easily decomposed in moist conditions, they must be properly encapsulated, which results in low stability.

To overcome those limitations and speed up the commercialization of perovskite solar cells, professor Jin Young Kim from the School of Energy and Chemical Engineering at Ulsan National Institute of Science and Technology (UNIST, Ulsan, South Korea; www.unist.ac.kr) and associates from Wonkwang University (Iksan) and the Korea Institute of Energy Research (KIER; Ulsan, both South Korea) have used fluorine-functionalized graphene nanoplatelets (EFGnPs-F) with a p-i-n structure of perovskite solar cells to fully cover the perovskite active layer and protect against water ingress. The cells achieved 82% stability relative to initial performance over 30 days of air exposure without encapsulation.

The enhanced stability resulted from fluorine-substitution on EFGnPs. "By substituting carbon for fluorine, we have created a two-dimensional material with high hydrophobicity, like Teflon, and then applied it to perovskite solar cells," says a member of the research team, professor Gwi-Hwan Kim at UNIST.

The newly-developed perovskite solar cell device was fabricated using a solution process, in which the perovskite material is coated onto on a flexible film. This process will allow applying solar cells to wearable devices. A simple manufacturing process and a low manufacturing cost distinguishes the new devices from existing silicon-based inorganic electronic devices.

Testing tide power

A counter-rotating propeller technology that is being developed to harness the energy from tidal currents has been field tested off the coast of Nagasaki Bay, near Iwo Jima, Japan. The prototype, which is one seventh the size of a commercial unit, has a rated power of 500 kW and was shown to have a 43.1% power generation efficiency for a water flowrate of 4 m/s, which exceeded the estimates (42%) based on the design. The device was developed by a Japanese industry-academia-government collaboration, led by Kyowa Engineering Consultants Co. (Tokyo) and the New Energy and Industrial Technology Development Organization (NEDO; Kawasaki; www.nedo.go.jp), with partners EIM Electric Co., Maeda Corp. Kyushu Institute of Technology and Waseda University. The unit has two 5-m-dia. propellers that rotate in opposite directions when water flows through. The design has the advantages that not only the output is sufficiently higher without supplementary equipment (such as a gearbox), but also the rotational moment hardly affects the support structure because the rotational torque of both propellers/armatures are counter-balanced in the unit.

The tests were conducted by towing the device by a ship, but ultimately stationary (floating) devices can utilize the ocean currents to generate next-generation electricity.

A promising zeolite for ethylene separation

Scientists from ExxonMobil (Irving, Tex.; www.exxonmobil.com) and the Institute of Chemical Technology (ITQ; Valencia, Spain; http://itq.upv-csic.es) have discovered a new material that could significantly reduce the amount of energy and emissions associated with the production of ethylene. Depending on the application, use of the new material, in conjunction with other novel separation processes, could result in up to a 25% reduction in both the energy needed to separate ethylene from ethane, as well as the associated CO_2 emissions. Results of the research have been published in a recent issue of *Science*.

The patented new material, ITQ-55, is a silica zeolite that can selectively adsorb ethylene over ethane as a result of its unique flexible pore structure. Built from heart-shaped cages interconnected by flexible elongated pore openings, the material allows the diffusion of the flatter ethylene molecules as opposed to the more cylindrical-shaped ethane molecules. The new material acts as a flexible molecular sieve, and has an unprecedented degree of selectivity at ambient temperature, says ExxonMobil.

Although more work is required before the new technology can be applied industrially, it could become an economically superior alternative to conventional cryogenic distillation, when further developed. ■

Business News

Plant Watch

Covestro invests in debottlenecking and chlorine supply at Tarragona site

December 11, 2017 — Covestro AG (Leverkusen, Germany; www.covestro.com) will invest around €200 million in improvement projects at its production site in Tarragona, Spain, including construction of an onsite chlorine-production plant and a debottlenecking project to increase methylene diphenyl diisocyanate (MDI) production by 50,000 metric tons per year (m.t./yr) to 220,000 m.t./yr. The chlorine plant is planned to start up in 2020, and the debottlenecking will occur through 2022.

NOVA announces plans for cracker expansion and new PE plant in Sarnia

December 8, 2017 — NOVA Chemicals Corp. (Calgary, Alta., Canada; www.novachem.com) announced two significant capital-investment projects in the Sarnia-Lambton region of Ontario, Canada. The expansion of NOVA Chemicals' Corunna cracker by approximately 50% will provide ethylene for a new polyethylene (PE) production facility. The new plant is designed to increase NOVA Chemicals' PE production capacity by approximately 450,000 m.t./yr. Site preparations are currently underway for both projects, with startup targeted for late 2021.

Clariant selected by Xuzhou HaiDing for new PDH unit in China

December 8, 2017 — Clariant AG (Munich, Germany; www.clariant.com) will develop a custom-built Catofin catalyst and propane dehydrogenation (PDH) unit in cooperation with CB&I (The Woodlands, Tex.; www.cbi.com) for Xuzhou HaiDing Chemical Technology Co. The project includes the license and engineering design of the unit, which is to be built in Pizhou, Jiangsu Province, China. The Xuzhou HaiDing plant is designed to produce 600,000 m.t./yr of propylene (PP).

BP to build its third lubricants plant in China

December 7, 2017 — BP plc (London; www.bp.com) plans to build a new lubricants-blending plant in China. The new plant will be BP's third lubricants-blending plant in China, and with an expected investment of around $230 million, will also represent BP's single largest blending-plant investment worldwide. The new plant, expected to start operation before the end of 2021, will have a production capacity of 200,000 m.t./yr.

Oxea to begin DOTP production in Europe

December 5, 2017 — Oxea GmbH (Monheim am Rhein, Germany; www.oxea-chemicals.com) entered into a cooperation with a German partner to produce dioctyl terephthalate (DOTP), a non-*ortho*-phthalate plasticizer. By 2019, Oxea will produce 60,000 m.t./yr of DOTP. For this project, Oxea's cooperation partner will construct a modular DOTP production unit at its manufacturing site in Germany.

thyssenkrupp to build two major polymer plants for SASA in Turkey

November 30, 2017 — thyssenkrupp Industrial Solutions' (Essen Germany; www.thyssenkrupp-industrial-solutions.com) subsidiary Uhde Inventa-Fischer signed a contract to build two new world-scale polymer plants for SASA Polyester Sanayi A.S. in Adana, Turkey. One plant is planned to produce 380,000 m.t./yr of polyethylene terephthalate (PET) for low-viscosity applications. The second plant will use proprietary technology to produce 216,000 m.t./yr of resin for the production of PET bottles.

W.R. Grace awarded Unipol PP contracts in Kuwait and China

November 28, 2017 — W.R. Grace & Co. (Columbia, Md.; www.grace.com) will license its Unipol PP process to Kuwait Integrated Petroleum Industries Co. (KIPIC) for the integrated petrochemical complex at its Al-Zour petroleum refinery. Expected to open in 2023, the facility is designed to produce 940,000 m.t./yr of polypropylene. W.R. Grace also announced two Unipol PP licenses in China — one from Sinochem Quanzhou Petrochemical Co. and one from Oriental Energy Co. in Ningbo.

Lotte Versalis Elastomers opens new production plant in South Korea

November 27, 2017 — Lotte Versalis Elastomers, a 50-50 joint venture (JV) between Eni S.p.A. (Rome, Italy; www.eni.com) and Lotte Chemical (Seoul, South Korea; www.lottechem.com), opened a new integrated industrial complex for the production of elastomers in Yeosu, South Korea. The industrial complex has a nameplate capacity of 200,000 m.t./yr of elastomers, including ethylene-propylene diene monomer (EPDM) and solution-styrene butadiene rubber (s-SBR).

Mergers & Acquisitions

Atlas Copco acquires mining equipment businesses in the U.S. and South Africa

December 4, 2017 — Atlas Copco AB (Stockholm, Sweden; www.atlascopco.com) intends to acquire Cate Drilling Solutions LLC, a distributor of mining equipment, and Renegade Drilling Supplies Proprietary Ltd., a manufacturer of mining equipment and accessories. The acquisition of Utah-based Cate Drilling Solutions is expected to close in early 2018. Based in Johannesburg, South Africa, Renegade

LINEUP

3M
AKZONOBEL
ATLAS COPCO
BP
CB&I
CLARIANT
COVESTRO
ENI
EVONIK
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Drilling specializes in consuables, such as drill rods and diamond drill bits.

BP Biofuels and Copersucar form ethanol JV in Brazil

December 1, 2017 — BP Biofuels and Copersucar (www.copersucar.com.br) agreed to form a JV to own and operate a major ethanol storage terminal in Brazil. The 50-50 JV will own and operate the Terminal Copersucar de Etanol in Paulínia in the state of São Paulo. The Paulínia terminal has ten ethanol tanks with a total storage capacity of 180 million L and transports around 2.3 billion L/yr, with the potential for further expansion.

Umicore to sell its European Technical Materials business

December 1, 2017 — Umicore N.V. (Brussels, Belgium; www.umicore.com) has agreed to sell its European Technical Materials business to Saxonia Edelmetalle GmbH, a German refiner and manufacturer of precious-metal chemical compounds, semi-finished products and contact parts. The agreement concerns operating assets in Germany and Italy that manufacture contact materials and brazing alloys for technical applications. The business generated €163 million in 2016. Closing of the transaction is expected in the first quarter of 2018.

Evonik to acquire additive compounding business from 3M

November 28, 2017 — Evonik Industries AG (Essen, Germany; www.evonik.com) will acquire the high-concentrates additive compounding business of 3M (St. Paul, Minn.; www.3m.com). The deal includes the Accurel brand product portfolio and a production plant in Obernburg, Germany. The high-concentrates additive compounding technology allows plastic manufacturers to introduce large volumes of additives into a polymer matrix via a solid polymer carrier.

AkzoNobel acquires powder coatings company in Thailand

November 27, 2017 — AkzoNobel N.V. (Amsterdam, the Netherlands; www.akzonobel.com) has agreed to acquire the business of V.Powdertech Co., a leading manufacturer of powder coatings in Thailand. The transaction includes all relevant technologies, patents and trademarks, as well as a manufacturing plant in Samutsakhon, Thailand. In addition, all employees from V.Powdertech will be joining AkzoNobel.

LyondellBasell and SUEZ buy European plastics-recycling business

November 27, 2017 — LyondellBasell (Rotterdam, the Netherlands; www.lyondellbasell.com) has entered into a definitive agreement to purchase a 50% stake in Quality Circular Polymers (QCP), a plastics recycling company in Sittard-Geleen, the Netherlands. Under the terms of the agreement, LyondellBasell will be a 50-50 partner in QCP with SUEZ (Paris, France; www.suez-environnement.fr). Starting in 2018, QCP's Sittard-Geleen facility will begin converting consumer waste into 35,000 m.t./yr of PP and high-density polyethylene (HDPE).

Pressure Measurement Gets Rugged, Goes Digital

Innovations place more robust instruments in demanding applications and enable processors to take advantage of the industrial internet of things

Because pressure is one of the most common and important measurement parameter in a chemical processing plant, the established technology has been providing top-notch accuracy of readings for some time now. However, because the chemical process industries (CPI) are always evolving, so too must the devices. For this reason, providers of pressure measurement equipment are tweaking standard technologies in an effort to meet the requirements of more demanding chemical applications. At the same time, digitalization is being added to many devices, providing more advanced diagnostics and allowing users to dive into the industrial internet of things (IIoT).

WIKA Instrument

FIGURE 1. WIKA's double-diaphragm design with diaphragm monitoring system offers a solution for applications where the product must not find its way into the environment, or where the fill fluid in the diaphragm seal assembly must not come in contact with the product for any reason

IN BRIEF

CAPTURING DEMANDING APPLICATIONS

THE AGE OF DIGITALIZATION

Conquering demanding applications

"In the chemical and [petroleum] refining industries, we are seeing the pressure devices exposed to much more demanding process conditions and applications," says Scott Nelson, vice president and general manager of pressure products with Rosemount, Inc., (Shakopee, Minn.; www.emerson.com), a subsidiary of Emerson. "As our customers try to drive less variability, run cleaner processes and achieve higher efficiencies, they tend to run at higher operating temperatures and higher pressures, which greatly exceed the normal limits of field instrumentation."

For example, Nelson says, in the chemical industry, a typical pressure instrument will have a process temperature limit of 120°C, so manufacturers of pressure instrumentation have been tasked with developing solutions that will allow operation in much hotter processes, some as high as 410°C. "That is really pushing the envelope to what we've seen in the past," he says.

Tony Maupin, chemical market segment manager, with WIKA Instrument, LP (Lawrenceville, Ga.; www.wika.com) adds that in addition to developing new technologies designed to address more challenging applications, increasing safety concerns and the needs of niche applications are also driving innovation.

"One of the most important characteristics of pressure measurement devices is reliability in notoriously harsh conditions, including high temperatures, high pressures and corrosive materials," says David Wilson, product manager for pressure and temperature products with SOR Inc. (Lenexa, Kan.; www.sorinc.com). "Since most devices are currently very accurate, the focus is on making sure the device remains stable, efficient and safe in these difficult conditions."

One of the ways equipment providers are doing that is through providing diaphragm seals with the devices and making those seals in a variety of materials or with innovations that allow them to withstand the chemical-processing environment. "The diaphragm seal protects the instrument from temperature, corrosive media and other process conditions that could damage or affect the sensor's accuracy or the life of the sensor itself. Diaphragm seals are add-on accessories, but selecting the right material and design will help prolong the life and increase the safety of challenging applications," says Wilson.

In chemical processes, fluctuating temperatures, aggressive media or strong vibrations often decrease safety and accuracy of readings, says Ehren Kiker, product marketing manager with Endress + Hauser (Greenwood, Ind.; www.us.endress.com).

Rosemount/Emerson

FIGURE 2. Rosemount's Wireless Pressure Gauge features up to 150 times overpressure protection and two layers of process isolation, providing a safer installation

To measure more precisely in such applications and to increase process safety, the company developed a temperature compensating membrane, called TempC. "Instead of flexing symmetrically like a normal remote seal, these flex asymmetrically," explains Kiker. "This allows the diaphragm to handle ambient and process temperature changes without causing huge shifts in measurement, providing accurate and stable measurements. Fast membrane recovery after temperature shocks of the diaphragm also permits shorter downtime in batch applications, providing higher availability of production, as well."

And, because safety is an ever-increasing concern, especially in chemical processing, manufacturers like WIKA are taking steps to provide solutions for critical or aggressive applications. WIKA's double-diaphragm design with a diaphragm-monitoring system offers a solution for applications where the product must not find its way into the environment, or where the fill fluid in the diaphragm seal assembly must not come into contact with the product for any reason (Figure 1). The space between the inner and outer diaphragms is evacuated. The resulting vacuum is monitored by a measuring device, such as a pressure switch, gage or transmitter. Should an outer diaphragm breach occur, a visual, acoustic or electrical

Endress + Hauser

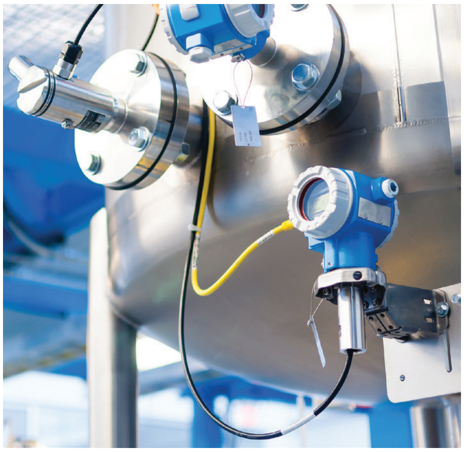


FIGURE 3. Endress + Hauser's electronic DP Deltabar FMD72 differential pressure system measures pressure, level, volume or mass in pressurized tanks, distillation columns and evaporators to eliminate issues regarding ambient and process temperature effect, which can cause measurement drift and inaccuracies

warning will be given. The damaged system can then be replaced during the next shutdown. "While this isn't something that every chemical process needs, in niche applications where there is a particularly nasty acid or chemical that must not get out, the system gives the user an indicator that they have lost the first level of containment while the chemical is still being contained and they still have time to remedy the issue," says Maupin.

Also in an effort to improve reliability and robustness, equipment providers are improving more than the diaphragm seals. For example the Rosemount Wireless Pressure Gauge (Figure 2) features up to 150 times overpressure protection and two layers of process isolation, resulting in safer installation. "It is very easy to over-pressurize traditional pressure gage devices built on Bourdon-tube technology and cause them to break," says Rosemount's Nelson. "We have been able to bring our solid-state pressure sensor technology into the pressure gage market and offer a pressure gage that can be over-pressured up to 150 times and withstand 11,000 psi burst pressure. This means these pressure gage applications are able to withstand fault conditions and any sort of pressure spikes. They also have smart electronics on them so the gages are continuously diagnosing themselves and can communicate any problems to the user remotely via wireless."

And, if a processor is looking to eliminate issues regarding ambient and process temperature effect, which can cause measurement drift and inaccurate readings, Endress + Hauser offers an electronic dp Deltabar FMD72 differential pressure system for the measurement of pressure, level, volume or mass in pressurized tanks, distillation columns and evaporators (Figure 3). The high-pressure sensor measures the hydrostatic pressure. The low-pressure sensor measures the head pressure. The level is calculated in the transmitter using these two digital values. "Part of the reliability issue is inherent to seal systems because they are so susceptible to temperature issues," says E+H's Kiker. "This system is designed to minimize those issues in applications where temperature effect in remote seals provides challenges to users."

For applications where extreme temperatures create challenges, the Rosemount 3051S Thermal Range Expander enables the transmitter to operate in high-temperature processes without the need for heat tracing. The 3051S device uses a specialized process interface and fill fluid to withstand process temperatures ranging from –105 to 410°C and pressures up to 3,750 psi. "This is a great example of products that are being developed to help users deal with very demanding applications because it can withstand very high and very low temperatures, and users are able to simplify their processes by eliminating heat tracing equipment, which is often used in temperature-challenged applications," says Rosemount's Nelson.

The age of digitalization

Over the past decade, pressure transmitters, like other instruments, have been getting smarter via features such as time clocks, minimum and maximum pointers for pressure and temperature and other built-in intelligence that provided information to users. However, says Sean McNutt, product marketing manager for pressure measurement and control with Siemens (Alpharetta, Ga.; www.usa.siemens.com), the hard-

Siemens

FIGURE 4. Siemens Sitrans P DSIII digital pressure transmitter features ease of installation and set up, high accuracy and self-diagnostics and simulation functions

est part was getting that information out of the devices and into the users' hands in a usable way. "But with the move toward digitalization and the industrial internet of things (IIoT), there are new ways of getting data out of the transmitter, whether it's through a digital bus connection or via HART communications, and this is allowing industry to make the move from just going out and checking the devices to actively taking available data and using it in a way that improves efficiency and reliability of the instruments and the process," says McNutt.

SOR

FIGURE 5. SOR's 815PT Smart Pressure Transmitter is a rugged, compact, loop-powered instrument suitable for hazardous locations and hostile environments

He adds that while most pressure instruments typically don't provide enough information to necessitate Ethernet connections, many users are asking for connections with the ability to export information from the device to a monitoring system or to the cloud so they can get to and use the data that have been previously trapped in the transmitter. "These transmitters have had Profibus or HART for years and now we are adding components to existing networks, making it easier to get more functionality out of existing instruments and allowing users to do more with that data," says McNutt.

In addition to the ability to begin exploring the data, many of today's devices offer self-diagnostic or other smart features. For example, Siemens Sitrans P DSIII digital pressure transmitter (Figure 4) is available with HART, Profibus PA or Foundation Fieldbus communications. It features ease of installation and set up, high accuracy and self-diagnostics and simulation functions. It is suitable for

installation in SIL2 (safety integrity level) applications and comes with a range of safety approvals.

And, SOR's 815PT Smart Pressure Transmitter is a rugged, compact, loop-powered instrument suitable for hazardous locations and hostile environments. It is easily configured using HART 7 Communication Protocol and Modbus RTU Serial Communications. "One of the benefits of the communication capabilities is that it allows operators to perform predictive maintenance based on the data," says SOR's Wilson. "By monitoring the data they get from the device, users can now see when it is time for a product to be replaced or maintained, as opposed to just reacting to the failure of the instrument after the fact."

Similarly, many of Rosemount's pressure measurement devices offer intelligent features such as Power Advisory Diagnostics, which has the ability to monitor power supply and electrical connection to the device. If an incident occurs that could lead to a fault condition or loss of signal, the device can detect it and alert the user before the signal is lost. Statistical Process Monitoring is another feature available on Rosemount devices. SPM technology characterizes the normal operation of a process and continually monitors it to see if the process signature has changed, and does so at a much faster rate than is possible in the process control system. "This provides users with the ability to monitor and detect abnormal operating conditions and receive early detection of any problems that may be arising, not just in the device, but in the process and physical installation as well," says Nelson.

Data, such as those available from smart pressure devices and other instruments, enable the shift from reactive to predictive maintenance, says Siemen's McNutt. Because pressure transmitters have built-in diagnostics and alarms and timers and often provide realtime visualization of related systems, they can inform users about drifts in temperatures, pressures or calibration issues that need attention. In traditional analog measurements, users only received the process value and wouldn't know anything was wrong with the transmitter until it wasn't responding or until the process was off specification until it became obvious in other ways. "With more data about the instrument and the process available from pressure instruments, users can apply that to get a better look into the process itself and start to employ predictive maintenance instead of reactive," he says.

Nelson agrees that smarter transmitters provide high value in and of themselves as a measurement point and as another way to monitor various systems. He adds that recently they are being used to feed the IIoT with more process insight and actionable information that has already been analyzed. "This is no longer just raw data," he says. "It is usable information and the digitalization of that information is allowing us to enable the industrial internet of things." ■

Joy LePree

Bulk-Solids Handling

Hoppers promote effective flow of challenging materials

The Live Bin product line (photo) includes fully assembled and self-contained vibrating hoppers that are designed to promote the reliable flow of any dry material. Available capacities range from 3 to 100 ft^3 of bulk-solids storage. These bins can handle a diverse array of bulk solids, ranging from micron-sized particles to fibrous and flaky materials, and they discharge the contents on a "first-in/first-out" basis, ensuring mass flow and eliminating material segregation during operation, says the company. They can be used to discharge to any feeder or process line, or wherever a surge bin is required. Its design does not require a flexible seal, so it is especially suitable for sanitary applications, according to the manufacturer. — *Vibra Screw, Inc., Totowa, N.J.*
www.vibrascrew.com

Pneumatic control system ensures reliable discharging

The patented LAS-EC Big Bag Connection System (photo) provides an easy, ergonomic and safe way to discharge powders from Big Bags. Its patented pneumatic control system is simple to operate and has only three buttons — for connecting, sealing and disconnecting bags to the unit. During operation, the Big Bag is positioned and connected and its inner liner is fixed with the pneumatic sealing device. After the Big Bag is discharged, the bag is closed and the containment system is closed. — *Hecht Technologie GmbH, Pfaffenhofen, Germany*
www.hecht.eu

Heavy-duty chute diverter is undaunted by abrasive solids

The Pivoting Chute Diverter (photo), which is part of this company's Titan Series product line, is suitable for use with applications that involve the handling of materials that pose excessive abrasion and wear issues (such as alumina, bauxite, cement, clinker, coal, flyash, gravel, rock and many more). It is also appropriate for use in applications that call for extremely large valves or diverters, situations that require a valve to function reliably under especially harsh conditions, and other specialized heavy-duty applications. The body is constructed from carbon steel and the wetted parts are lined with one of many choices of abrasion-resistant metal. Its independent, internal pivoting chute is designed to improve processing speeds and provide a valve with longevity when operating in particularly wearing environments, says the manufacturer. Inspection, maintenance and repairs can be quickly and easily performed while the diverter remains inline, thanks to an access panel on the front of the diverter. It is available in either a two-way or three-way configuration. — *Vortex, Salina, Kan.*
www.vortexglobal.com

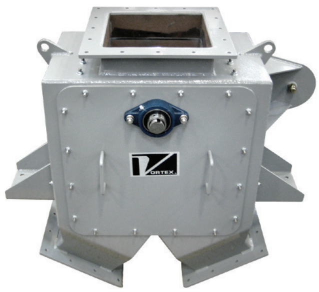
Dump station eliminates dust escape when handling solids

The Flexicon Bag Dump Station (photo) with NEMA 7/9 explosion-proof electrical system is designed to contain dust emitted from manual dumping stations, and help operators handle the empty bags (by compacting and consolidating them) and convey the materials to an elevated destination. Bags are staged on the tray and transferred into a hooded glove box and onto a grate, which supports the grate and prevents unintended operator contact with moving parts. The hood has a polycarbonate skylight that illuminates the interior of the enclosure for improved bag slitting, dumping and disposal. A bag infeed chute through the sidewall of the glove box permits the operator to pass empty bags directly into the integral bag compactor, helping any dust to be directed into the system's two filter cartridges. Useable product that builds up on the filter surfaces is periodically returned to the hopper, using timer-activated solenoid valves to release short blasts of compressed air inside the cartridges. The hopper

Vibra Screw



Hecht Technologie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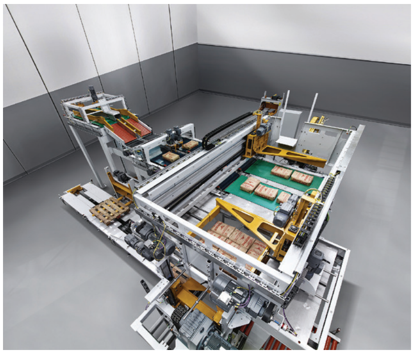
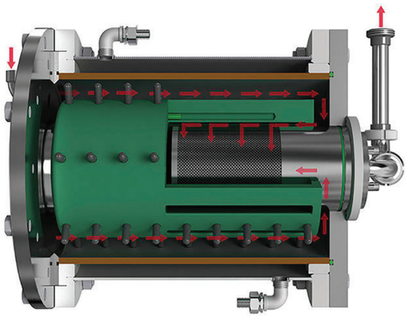
Flexicon

Note: For more information, circle the 3-digit number on p. 62, or use the website designation.

Beumer Group



The Witte Co.



Netzsch Premier Technologies

GEA Group AG

discharges into an enclosed flexible screw conveyor for dust-free transfer of free-flowing and non-free-flowing materials to an elevated destination. — *Flexicon Corp., Bethlehem, Pa.*
www.flexicon.com

System lets you fill, package and palletize bulk-solids bags

This company supplies complete packaging lines that carry out filling, packaging and palletizing in a single, integrated system. The Paletpac (photo) creates precise, stable, space-saving bag stacks, handling bags made of different paper and plastic materials and designs (such as flat-valve bags or valve-bottom bags). The Paletpac can be installed quickly, is intuitive to use, provides easy access for maintenance and can be flexibly adapted to different packing patterns, says the company. It can be equipped with a clamp-type turning device or a twin-belt turning device, to ensure gentle, fast, precise positioning of the bags. — *Beumer Group GmbH & Co. KG, Beckum, Germany*
www.beumergroup.com

Pneumatic cover lift provides safe access for dryer cleaning

The vibrating fluid-bed dryer (photo), which is designed for fine particle drying, has an integral baghouse dust collector, and now offers an optional pneumatic cover lift that automatically raises the cover with just the push of a button. This provides easy access and allows one person to roll the dryer forward on rails, out from under the dust collector, providing easy access for inspection and cleaning. This new feature eliminates the need for an overhead crane or other costly lift system, says the company. — *The Witte Co., Washington, N.J.*
www.witte.com

Circulating grinding system offers multi-pass operation

The Grinding System Zeta (photo) is designed to maximize size-reduction volume throughput without overheating the product. It uses extremely small (0.1– to 3–mm dia.) grinding media, and ensures reproducible product quality, says the company. The closed horizontal agitator bead mill is designed for the highest product throughput rates and has a peg grinding system that provides extremely high grinding intensity. The horizontal orientation guarantees a homogeneous fill of the grinding media in the grinding tank, says the manufacturer. For precise temperature control, the agitator mill is equipped with an optimized cooling system. The forced conveyance of the product through the grinding media fill guarantees a uniform load inside the mill, while the dynamic separation system retains the grinding media in the grinding zone. This enables extremely high throughput rates without pressure buildup and allows for multipass operation. — *Netzsch Premier Technologies LLC, Exton, Pa.*
www.netzsch.com

Compact spray dryer boasts increased throughput

The Mobile Minor MM-100 spray dryer (photo) has a compact footprint, and is equipped with a new and highly efficient cyclone, dubbed the Cyclone Extra Efficiency (CEE). The CEE offers a higher separation efficiency than standard cyclones, over a range of particle sizes, air flows and powder loadings, which increases the yield and reduces emissions, according to the manufacturer. The Mobile Minor MM-100 can operate with process gas flowrates of up to 100 kg/h at an inlet temperature of 200°C, which, for many products, means a 30% increase in powder production compared to the previous version. Higher-capacity HEPA filters are available, and powder-collection glasses in sizes from 250 to 3,500 mL can be supplied as standard. — *GEA Group AG, Düsseldorf, Germany*
www.gea.com

Single unit provides mixing and pumping of ingredients

The Hybrid Powder Mixer (photo; p. 17) is designed to accomplish several key functions — mixing and pumping of both wet and dry ingredients to produce a homogeneous blend — using only a single motor drive; conventional systems can require up to four separate electric motors, consuming a lot of energy. This unit can reduce power consumption by 50% compared to the conventional approach, and fewer components helps to reduce maintenance require-

ments. This mixer combines pump and powder-dissolving technologies in a single versatile unit. It is said to be the only hygienic powder mixer capable of drawing powder into the unit while simultaneously pumping the resulting process liquid at pressures up to 4 bars, eliminating the need for a separate discharge pump. It effectively pre-blends the powder and liquid before the mixture enters the high-shear stage, which contributes to faster and more-effective dissolution, according to the manufacturer. — *Alfa Laval Kolding A/S, Kolding, Denmark*
www.alfalaval.dk

Peruse the many offerings for hygienic powder processing

This company offers a diverse portfolio of engineering solutions to address the entire process chain for manufacturing and packaging of powders, pellets and tablets in the pharmaceutical, food and chemical industries. This includes systems for granulation, tabeleting, coating and primary, secondary and final packaging. —*Romaco Group, Karlsruhe, Germany*
www.romaco.com

Quick-change feeder can handle a large array of products

The T35/S60 Quick Change Feeder (photo) is designed for applications requiring the material-handling and changeover flexibilty along with the convenience of easy cleaning capability. It enables a fast disassembly, exchange and cleaning of the feeding module, which minimizes downtime and eliminates the risk of cross-contamination while allowing one feeding station to handle many different materials. Whereas single-screw feeding elements are ideal for handling free-flowing powders, granules, pellets and other non-flooding materials, they often don't work very well with more difficult-to-handle materials. Twin screw elements employing two self-wiping, closed-flight screws, intermeshed side by side, efficiently transport floodable powders, as well as sticky or otherwise hard-to-flow materials to the discharge. The QC-Feeder is available in both volumentric and loss-in-weight configurations. —*Coperion K-Tron, Sewell, N.J.*
www.coperion.com

Dense-phase conveyor system protects fragile materials

The E-finity low-pressure dense-phase conveyor system (photo) is designed to handle fragile materials safely, reliably and continuously. Precise pressure monitoring and airflow corrections allow the system to operate efficiently under a wide range of conditions, while gently inducing materials through the convey line in slug form. It is suited for granular and pelleted materials. The E-finity air controls can employ a single air source to operate two to three different systems simultaneously. This results in significant cost savings in both equipment and installation, with continued savings in operation and maintenance moving forward. — *Schenck Process LLC, Kansas City, Mo.*
www.schenckprocess.com

Vibratory feeder is the largest model in this product family

The Eriez 76 Series Vibratory Feeder (photo) is a versatile device that has applicability across a broad range of industries. It has become widely used with bucket elevators, as well as bulk-bag unloading, scale feeding and other challenging applications. This feeder supports trays of up to 200 lbs, and is offered in most common voltages. It easily handles larger trays with multiple features, such as screens, covers, inlet spouts and downspouts, with a single compact drive unit that is required by most bulk bag dischargers. — *Eriez, Erie, Pa.*
www.www.eriez.com

This unit provides reliable handling of long, uneven fibers

This company's innovative fiber feeder is designed for reliable feeding of carbon fibers, wood fibers, long carbon fibers and shredded film strips (waste from plastic film-production processes). To handle long fibers, the screw feeder uses a special screw, and a large, steep-walled hopper. Its design includes special postioning of the agitator in the hopper to promote optimal ingredient flow into the screw, says the manufacturer. — *Brabender Technologie, Duisburg, Germany*
www.brabender-technologie.com

Suzanne Shelley

Alfa Laval Kolding A/S

Coperion K-Tron

Schenck Process

Eriez

Endress+Hauser

These flowmeters have been updated for sterile processes

Proline 300 Coriolis and electromagnetic flow instruments (photo) have been updated for safety, enhanced measurement quality, device accessibility and GMP (good manufacturing practice) compliance for sterile processes. The flowmeters' hygienic 316L stainless-steel housings are optimized for reliability and they have been designed to support an optional IP69 ingress protection rating, making them impervious to water ingress from high-pressure washdown. The sensors are designed according to several international standards, and provide full GMP compliance for sterile processes. They offer simple integration into many applications through a wide range of digital conductivity protocols including EtherNet/IP. The design is optimized for cleaning and sterilization, offering full drainability even in near horizontal installations. Both the Coriolis and electromagnetic flowmeters are available in models suitable for clean-in-place (CIP) or steam-in-place (SIP) processes in hygienic and sterile process applications. — *Endress+Hauser Inc., Greenwood, Ind.*
www.us.endress.com

W.L. Gore & Associates

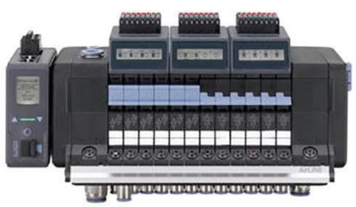
Protective venting for potentially explosive atmospheres

The PolyVent Ex+ (photo) is the newest addition to this company's line of screw-in protective venting. It has been certified to explosion-proof safety standards of IECEx and ATEX. The vents' rigorous certifications enable installation in areas with potentially explosive atmospheres caused by combustible gases or dust. The vent body and cap, as well as the patented membrane-sealing system, are constructed of 316L stainless steel. The membrane is made from ePTFE and provides stable pressure equalization, along with long-lasting oleophobic and hydrophobic protection. The membrane is rated for an airflow rate of 1,600 mL/min at 70 mbars. A silicone O-ring with a high flammability-resistance rating adds another layer of safety. — *W.L. Gore & Associates, Newark, Del.*
www.gore.com

Kemutec Group

This ribbon mixer features novel trough geometry

The Gardner HE Series of U-trough ribbon mixers (photo) has mixing troughs with unconventional short aspect ratios (length to diameter). Short mixing times combined with low-energy, gentle action and high efficiency ensure that minor ingredients are dispersed homogeneously without the need for pre-mixing, says the manufacturer. The mixer is equipped with a high-efficiency "double helix" agitator that has only six mixing blades. The Gardner HE Series has capacities ranging from 50 to 20,000 L. The mixer also features a large top cover for ease of access and is suitable for handling sticky powders. — *Kemutec Group Inc., Bristol, Pa.*
www.kemutecusa.com



Bürkert Fluid Control Systems

A valve island with monitoring and diagnostic functions

The AirLINE Type 8562 (photo) is a new valve island for control cabinets. Type 8652 was designed for applications in the water-treatment, pharmaceutical, cosmetics and food-and-beverage industries. It offers user-adjustable, integrated monitoring and diagnostic functions that improve system availability and process reliability, while also enabling preventive maintenance. An integrated display shows detailed onsite information, such as the current-switching statuses of the pilot and process valve, and issues a message if pre-set pressure-limit values are exceeded. The valve island is significantly smaller than its predecessor, says the manufacturer, and therefore fits into compact control cabinets that can be placed close to process valves. The valve island communicates via common industrial Ethernet protocols or Profibus DP. Each valve can be replaced during live operation without shutting down the system. As an additional safety function, check valves are used in the exhaust channel to prevent the unwanted activation of valves by pressure peaks and the resulting mixing of media. This also provides reliability on the pneumatic side. — *Bürkert Fluid Control Systems, Ingelfingen, Germany*
www.burkert.com

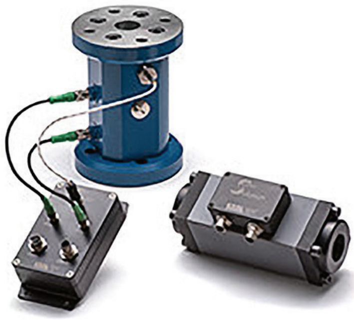
An online portal for corrosion management best practices

Impact Plus is a new platform designed to benchmark best practices and improve corrosion management across many industry sectors. Built as a tool for management professionals, the program gives users the option to manage their own application of the product or use a trained navigator with corrosion management and consulting expertise. Navigators will help users evaluate and compare their current asset-management strategies and advise them on future asset-protection and corrosion-management strategies. Features of the Impact Plus portal include: an integrated platform for corrosion management professionals; a straightforward way for companies to identify gaps in processes that could lead to the reduced lifecycle of assets due to mechanical, integrity or human error; a maturity model that creates a roadmap of activities, investments and best practices that lead to higher performance and a reference library to manage knowledge and information collected through all components of the portal. — *NACE International, Houston*
www.nace-impact.org

A new electronics unit for flowmeters

The KRAL Smart Solution (photo) is a compact electronic unit to which a Volumeter flowmeter is connected. The Smart Solution processes the signals that the flowmeter generates with its integrated sensors in such a manner that measured values are available that can be passed on via the Modbus. Up to 32 Smart Solution electronic units can be switched in series and thus save a multitude of cabling and their installation in comparison to conventional measured data acquisition. The flowmeters supply very precise measured values like the flow quantity, the flow direction and temperature to the Smart Solution, which processes this information into a flow value. — *KRAL AG, Lustenau, Austria*
www.kral.at

KRAL



New versions of data-analytics software launched

SIMCA is an advanced data analytics and visualization program (photo) that makes it possible to combine and analyze data from all sources to isolate, understand and act on the "hidden gems" that hold the secret to better decision-making and greater business success. SIMCA's multivariate data-analysis engine enables companies to swiftly detect and analyze deviations from normal operating conditions by modeling an idealized process. Once this model is transferred into SIMCA-online, it serves as a valuable reference for users' current production. The newly enhanced software offers an intuitive graphical interface and the flexibility to handle complex data, such as reworking, splitting and merging, and more. SIMCA projects can be uploaded directly to an available SIMCA-online server.— *Sartorius Stedim Biotech, Göttingen, Germany*
www.sartorius.com

Sartorius Stedim Biotech

Identifying licensees for new inventions just became automated

Licensee Locator is an analysis tool that enables users to identify and locate potential acquirers or licensees for patented technology. Licensee Locator playbook takes any patent or technology description and automatically identifies potential acquirers or licensees, based on objective metrics of licensability, revealing suitable organizations that may not otherwise have been considered. This is made possible by its ability to process hundreds of millions of data points about all possible licensees — expanding the potential for commercialization far beyond the patent owner's existing network. — *PatSnap, London, U.K.*
www.patsnap.com

Simulation-based operator training for separators

SmartSIM (photo) is a sophisticated solution for efficient implementation of new machine-control systems or optimized training of new operators. It is available for various models of solid-liquid separation machines and systems with a Metris addIQ control system. Among the benefits of SmartSIM training are reduced downtimes, because there are fewer operating errors and lower maintenance costs due to operators being highly trained. Smart-

Andritz

Fluke

Phoenix Contact

Pall

Siemens AG

SIM includes a computer-assisted classroom training course, which can be used at any time without affecting actual plant operation. Using the original operating interface, trainees have the opportunity to control a "digital twin" of the machine, including the individual parameters of production operations. In the course of the training, participants learn — with on-site support from this company — how to run the machine, respond properly to alarm situations, and improve the performance of the machine or the process. — *Andritz AG, Raaba-Grambach, Austria*
www.andritz.com

Monitor equipment health with this wireless sensor

Vibration screening is one of the most effective ways to detect and prevent equipment failures or downtime, but performing vibration analysis can be complex. The new 3560 FC Vibration Sensor (photo) wirelessly and remotely captures simple vibration screening data on imbalance and misalignment. Remote vibration monitoring allows maintenance managers to monitor asset health with ease and reduce the reliance on vibration specialists. The wireless sensor is small enough to fit in hard-to-reach places and affordable enough to place on multiple locations on equipment. The generated data are wirelessly transmitted and stored on the company's Connect Condition Monitoring software. — *Fluke Corp., Everett, Wash.*
www.fluke.com

The launch of a new cloud-based safety solution

With this company's cloud-based solutions, status information on standard and safety functions are transmitted continuously via a Profinet control solution to the Proficloud (photo). This information is then evaluated there. Thanks to the holistic consideration of resources and machinery, completely new opportunities are opened up for operators and designers to increase operational performance. This enables, for example, the determination of interdependencies between safety and process parameters. Or the monitoring of operational and maintenance processes across the entire line during normal operation. With access to this information, measures can then be derived and operational patterns determined. The machinery design can thus be optimized and work sequences designed to be more efficient. — *Phoenix Contact GmbH & Co.KG, Blomberg, Germany*
www.phoenixcontact.com

This fluid-monitoring platform is smart

The Crixus Fluid Monitoring Platform (photo) is a fluid-cleanliness management solution designed to provide industrial customers with intelligent fluid monitoring. The patent-pending fluid-monitoring platform meets the growing need for lubrication and hydraulic fluid cleanliness in industrial manufacturing equipment and filter performance. The Crixus provides realtime data that instantly flag performance issues and warns of potential problems. Information from the Cloud is pushed to the Crixus mobile and web app, where systems and applications from multiple sites can be monitored. — *Pall Corp., Port Washington, N.Y.*
www.crixus-pall.com

Simulation for faster commissioning and training

This company has upgraded its Simit simulation platform for virtual commissioning and operator training (photo) with a new release. Version 9.1 enables Simit to also be used for virtual commissioning and operator training in modular plants, speeding up actual commissioning by as much as 60% and reducing unwanted standstill periods to a minimum, particularly during plant conversion and migration processes, says the company. Simit can also be used to implement a realistic operator training system. Version 9.1 comes with an array of innovations designed to improve operating convenience, support simulation modeling and contribute to improved efficiency, openness and flexibility. — *Siemens AG, Munich, Germany*
www.siemens.com/simit

High-tech compounds resist explosive decompression

Elastomer seals that are used in valves, pipelines, fittings or pig traps have to face exceptionally high requirements. A

sudden decrease in pressure can lead to damage of the sealing, a phenomenon known as explosive decompression. The elastomer material is either torn in various places or has blistering on the surface (photo). Only high-tech sealing compounds that are especially tested and designed with very good physical properties can be used in this situation. This company has developed seven different high-tech compounds that were intensively tested and are resistant against explosive decompression. All of these seven high-tech compounds fulfill the NORSOK Standard M-710 requirements for resistance against explosive decompression. Furthermore, some of the compounds fulfil the API 6A and 6D standard, as well as the NACE TM 0297 (Explosive decompression) and TM 0187 (sour gas) standards. — *C. Otto Gehrckens (COG) GmbH & Co. KG, Pinneberg, Germany*
www.cog.de

New knife gate valve for mid-service mining applications

The new Clarkson SU10R polyurethane knife gate valve for mid-service applications eliminates the compromise between light-service and heavy-duty valves with a high-performance, low-maintenance, bi-directional, abrasion-resistant design. The two-piece body construction and field-replaceable snap-in liner design provides more reliable sealing than competing products. An integral seat-face seal eliminates the need for flange gaskets in many conventional flanged installations. This, along with an improved gland, will make the product particularly suitable for users across the mining spectrum, from alumina to coal, copper, gold, silver and uranium. The snap-in urethane liner design means that no special tools are required to replace the liner. The valves will initially be available in sizes ranging from 50 to 600 mm, and operate at 10 bars pressure and up to 80°C. — *Emerson, St. Louis, Mo.*
www.emerson.com

Enhanced version of a network-based control system

Scheduled for release this quarter, this enhanced version of the Stardom network-based control system (photo) will include a new E2 bus interface module that has been developed for use in FCN-500 autonomous controller extension units. This enables the construction of systems that have more I/O points and cover a wider area. Stardom is a network-based control system that consists of the FCN autonomous controller, the VDS web-based HMI and the FAST/TOOLS SCADA package. Since first releasing Stardom in 2001, the company has continued to improve the functions of this system to satisfy its users' evolving needs. One such recent need is for the collective monitoring and control of applications where many different input and output devices are distributed over a wide area, in locations where conditions are often harsh. Other needs have included the reduction of wiring and maintenance costs while ensuring high reliability. — *Yokogawa Electric Corp., Tokyo, Japan*
www.yokogawa.com

Counter costs of metal corrosion with this technology

This company's Vapor-phase Corrosion Inhibitor (VpCI) Technology turns basic packaging materials like paper, cardboard boxes and plastic bags into corrosion-inhibiting tools that protect by vapor phase action without the direct application of a rust preventative or coating to the metal. One special means for creating effective corrosion inhibiting packaging is CorShield 352 coating for paper and corrugated cardboard, which is powered by Nano VpCI, a coating that contains multi-metal Vapor-phase Corrosion Inhibitors. Applied to normal Kraft paper or linerboard, CorShield 352 Coating creates an excellent protective material for interleaving or individually packaging metal parts. When metal articles are enclosed within flexible packaging or corrugated boxes coated with CorShield 352, protective molecules from the VpCI coating vaporize off the packaging material to provide complete corrosion protection to enclosed metals. — *Cortec Corp., St. Paul, Minn.*
www.cortecvci.com

Mary Page Bailey and Gerald Ondrey

COG

Yokogawa Electric

Cortec

Process Commercialization:

The 2017 Kirkpatrick Chemical Engineering Achievement Award

IN BRIEF

CB&I AND ALBEMARLE

CHEMETRY

DOW (CANVERA)

DOW (PARALOID)

MICROVI

PRAXAIR

The path to commercialization can be long and arduous, which means the engineers and chemists taking the path must have a good deal of patience, dedication and fortitude. To honor the efforts of those chemical engineers and their companies that have sucessfully commercialized a new process for the first time, *Chemical Engineering* magazine has been bestowing its Kirkpatrick Chemical Engineering Achievement Award since 1933.

The aim of the Award is to recognize and honor the most noteworthy chemical-engineering technology commercialized anywhere in the world during the two years prior to a given award year. The results for the 2017 Kirkpatrick Chemical Engineering Achievement Award are as follows:

Winning Award

- CB&I (The Woodlands, Texas; www.cbi.com) and Albemarle Corp. (Charlotte, N.C.; www.albemarle.com), for the AlkyClean process — the world's first solid catalyst alkylation process

Honor Awards

- Chemetry Corp. (Moss Landing, Calif.; www.chemetrycorp.com): eShuttle technology
- The Dow Chemical Company (Midland, Mich.; www.dow.com): Canvera polyolefin dispersion technology
- The Dow Chemical Company: Paraloid Edge Technology
- Microvi Biotech Inc. (Union City, Calif.; www.microvi.com): Denitrovi biocatalytic nitrate removal
- Praxair, Inc. (Danbury, Conn.; www.praxair.com): Oxygen-fired combustion process with thermochemical regenerators

These companies join the long and distinguished roster of past winners, which includes such milestones as Lucite International for its Alpha process for making methyl methacrylate (2009); Cargill Dow LLC for its production of thermoplastic resin from corn (2003); Monsanto hollow-fiber membranes for gas separation (1981); Union Carbide low-pressure low-density polyethylene (1979); M.W. Kellogg single-train ammonia plants (1967); Linde zeolite adsorbents (1961); the U.S. synthetic rubber industry (1943); and Standard Oil Development Co. aviation fuels (1939). A complete list of all past winners can be found online at: www.chemengonline.com/kirkpatrick-award.

Although the staff of *Chemical Engineering* organizes and bestows the award, neither the editors nor others associated with the magazine play any role in the selection or judging of the winner. Instead, the winner is selected by a Board of Judges (BOJ) comprised of current chairs of chemical engineering departments at accredited U.S. and E.U. universities. The members of the BOJ are, in turn, selected by over a hundred chemical engineering department chairs of accredited U.S. and E.U. universities. It is this unbiased selection process, combined with a more than 84-year tradition that makes the Kirkpatrick Award one of the most prestigious honors that a chemical process industries (CPI) company can receive.

This article presents more details about the process technologies honored in 2017.

2017 BOARD OF JUDGES

Lorenz T. Biegler, Carnegie Mellon University
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WINNING ACHIEVEMENT
CB&I and Albemarle: AlkyClean® alkylation technology

AlkyClean gasoline alkylation technology is an advanced solid-catalyst alkylation process for the production of motor fuel alkylate. With AlkyClean technology, light olefins from typical petroleum-refinery sources, such as fluid catalytic cracking (FCC) units react with isoparaffins to produce alkylate. Of primary interest is the reaction of butylenes with isobutane to form high-octane trimethylpentane isomers.

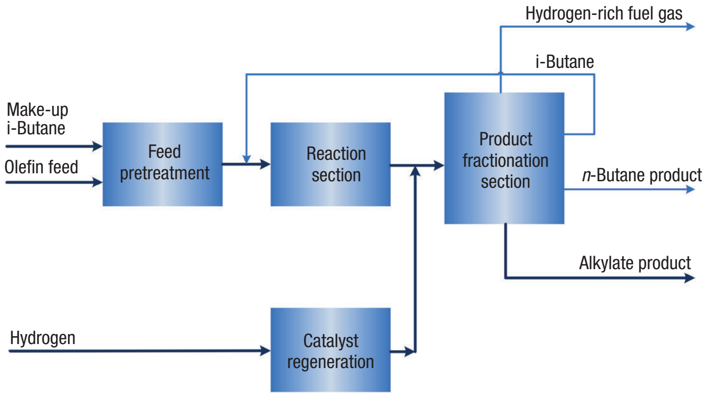
General description. The novelty and success of the AlkyClean technology is the ability of petroleum refiners to completely eliminate the use of liquid acids (H_2SO_4 or HF) and their associated hazards and operational complexity. Solid catalyst is used in multiple fixed-bed reactors, operating in cyclical mode, to continuously produce high-quality alkylate, while those off-line are being regenerated. The chemical engineering challenge was to create the ability to fully recover catalyst activity over multiple cycles. Breakthroughs made with the catalyst formulation and the regeneration process make this possible.

For decades, scientists have been trying to replace liquid acid technologies with a safer and more environmentally friendly solid catalyst technology. HF, in particular, is extremely toxic and, upon release, forms clouds that can be lethal for miles. Prior approaches with solid catalyst failed because of poor product selectivity or inability to fully recover catalyst activity. In some cases, these catalysts also used leachable corrosive components that could migrate into the product.

CB&I and Albemarle offer a catalyst/process combination that eliminates these drawbacks entirely. Furthermore, neither acid-soluble oils, nor spent acids, are produced and there is no need for product post-treatment of any kind. Without these waste streams and the need for post-treatment, corrosion is virtually eliminated in the downstream fractionation section. With the use of particulate catalyst, liquid acids are no longer required.

Albemarle's AlkyStar® catalyst has been designed for exclusive use with the AlkyClean process. It uses a zeolite that is well proven in the industry, along with a low concentration of a noble metal component. The strength, type and number of the zeolite's acid sites on the catalyst are optimized to enhance hydrogen transfer reactions over multiple alkylation reactions.

The process. The AlkyClean process consists of four main sections (Figure 1): reaction, catalyst regeneration, product distillation and an optional feedstock pretreatment section (depending on the quality of the olefin feed). Olefin feed, together with isobutane recycle, enters the reaction section. The reactor operates in liquid phase in the temperature range of 50 to 90°C and a pressure of 20–30 barg. These operating conditions are quite mild and typical of other processing units within a refinery. In the AlkyClean process, multiple reactors are used to allow for continuous alkylate production, as individual reactors cycle between online alkylation and low-temperature regeneration.



CB&I

FIGURE 1. The four main sections of the AlkyClean process are shown here

During regeneration, olefin addition is stopped and H_2 added to achieve a low concentration of H_2 in the reactor, while maintaining liquid-phase alkylation reaction conditions. This allows for a seamless switchover between alkylation and regeneration, while minimizing energy consumption. During low-temperature regeneration, H_2 cleans the catalyst, thereby delaying the buildup of longer-chain hydrocarbons.

Over time, however, there is still a gradual loss of catalyst activity, which is recovered by taking the reactor off line for a high-temperature regeneration step, which fully restores the catalyst activity. With this innovative continuous regeneration scheme, the performance is maintained without any disturbances to plant operation. The swing reactor, coupled with long catalyst life, allows the refiner to tailor turnarounds in line with FCC requirements.

Development and commercialization. The AlkyClean process and catalyst were developed at Albemarle's research center in Amsterdam with more than 60,000 h of operation on a small bench-scale pilot unit. In addition, a 10-bbl/d demonstration unit was operated in Porvoo, Finland on an actual refinery butylene stream for over two years. The data collected were used by CB&I to finalize the design basis for the technology and to successfully scale up to a commercial-sized plant.

The first commercial AlkyClean unit successfully started up in August, 2015, in Zibo, China by Shandong Wonfull Petrochemical Group Co. (Figure 2, and cover image).

CB&I

CB&I

FIGURE 2. The two photos show the first commercial plant to use the AlkyClean process. This 2,700-bbl/d unit started up in 2015 in Zibo, China and has now been operating safely and successfully for over two years, producing an alkylate product at a quality on par with existing technologies, and meeting or exceeding all process guarantees. The RON (octane) value of the alkylate product is typically in the 95 to 97 range

HONOR ACHIEVEMENTS

Chemetry: eShuttle™ technology

Chemetry's eShuttle technology provides a breakthrough in the synthesis of chlorinated organic compounds by eliminating chlorine generation from the traditional chlor-alkali process. The first commercial application of the technology is the chlorine-free synthesis of ethylene dichloride (EDC), an intermediate in the production of polyvinyl chloride (PVC). The next application for this platform, a process producing propylene oxide, is now in development.

General description. eShuttle replaces the chlor-alkali and direct-chlorination processes with a single, integrated process (Figure 3) that uses a circulating stream of aqueous copper chloride to transfer chloride ions from NaCl to ethylene. Specifically, the process leverages the redox states of copper to convert CuCl to $CuCl_2$ at the anode of the electrochemical cell. The $CuCl_2$ then reacts with ethylene to form EDC, regenerating the CuCl, which is returned to the cell. Like the processes it replaces, the eShuttle technology uses the same feedstocks — NaCl brine, water and ethylene — to produce the same products — EDC, caustic, and H_2 — but at much lower energy and operating cost and without Cl_2 gas generation.

The novelty of the technology lies in the elimination of Cl_2 as a chemical intermediate. By replacing the standard chlor-alkali anode reaction, $2Cl^- \rightarrow Cl_2 + 2e^-$, with the copper oxidation reaction, $Cu^+ \rightarrow Cu^{2+} + e^-$, the theoretical anodic voltage is decreased by 0.6V. This voltage translates directly to electrical savings of 25% and significantly lower operating costs. Moreover, the elimination of Cl_2 as an intermediate reduces the safety risk and costs associated with Cl_2 compression, storage and transportation.

Cell technology. From a chemical engineering perspective, one of the most important advances in the development of the new cell is the anode structure. Unlike traditional chlor-alkali cells, which have gas-generating reactions at both the cathode (H_2) and anode (Cl_2), the eShuttle cell does not generate gas at the anode. This provides two significant benefits to the cell design. First, the anode half-cell reaction is strictly an electron-transfer reaction; it is non-catalytic. As a result, catalytic coatings are not needed to assist with any reaction step, including gas desorption. Secondly, the anode compartment itself can be much thinner because there are no issues with two-phase flow. This is important because a three-compartment cell would typically lead to a much thicker cell. However, the thinner anode compartment actually allows for a cell that is about half the thickness of the state-of-the-art chlor-alkali cell. This allows the eShuttle to be readily retrofittable to existing electrolyzer floor space.

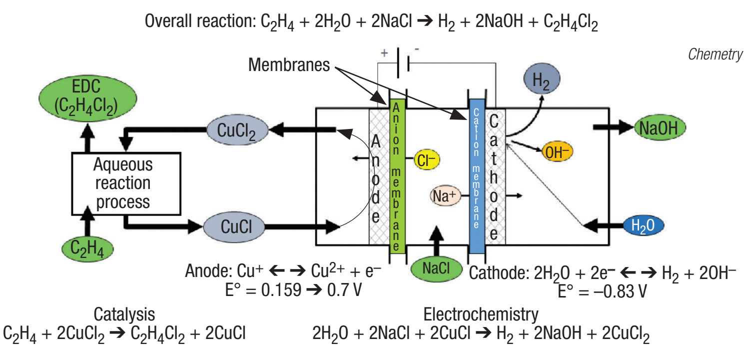
Although a single-phase anolyte does have benefits, it also presents two key challenges: mass transfer and pressure balancing. The gas generation in the chlor-alkali anode provides effective mass transfer through convective flows. Without gas generation, a thick, stagnant boundary layer may form at the anode surface. Formation of such a boundary layer can lead to localized depletion of Cu^{+1}, and diffusion-limited cell performance. To address these challenges, Chemetry utilized 3-D computational fluid dynamics (CFD) models to simulate various anode design concepts. The final design incorporates optimized electrodes with a bridged, corrugated mesh that acts as an inline static mixer for the flow. The design is optimized for high mass transfer and low pressure drop, and features an anion exchange membrane that has low resistance for Cl^- transport and yet blocks the migration of copper species, and a design that minimizes electrical losses and cell thickness.

Development and commercialization. The eShuttle process was transferred from laboratory to commercial demonstration scale at Chemetry's facility in Moss Landing, Calif. with integrated operation beginning in 2014 and extensive production campaigns in 2015.

To bring the process to commercial scale, Chemetry has developed partnerships with a number of key suppliers, including FuMA-Tech for the supply of membranes, Covestro for the supply of oxygen-depolarized cathodes, and a specialized laser welding company for cell fabrication. In 2016, TechnipFMC obtained rights to license eShuttle for EDC. Recently, a confidential development partner has signed a term sheet to install a demonstration-scale plant at one of its existing production sites.

FIGURE 3. The electrochemical cell of eShuttle is shown here

Chemetry



The Dow Chemical Company: Canvera™ polyolefin dispersions

Steel and aluminum containers for food and beverages are, and have been coated on the inside to protect against corrosion caused by the contents, and also to protect the contents from contact with the metal, ensuring preservation, flavor, quality and consumer food safety. Today, most interior coatings utilize epoxy, which contains bisphenol-A (BPA), which is a material of concern to some consumers.

Canvera polyolefin dispersions are made by a new manufacturing process, allowing food-and-beverage brand owners to address growing consumer interest in avoiding packaging that contains epoxy and BPA coating systems. Canvera polyolefin dispersions replace reactive, thermoset materials with high-molecular-weight thermoplastic polyolefin materials.

Polyethylene (PE) used in packaging avoids the reactive monomer issue present in thermosets. PE is made catalytically and the ethylene monomer is very volatile. The key process advance overcomes the difficulty of applying a polymerized solid to the inside of a can by forming a low-viscosity emulsion. The emulsion is easily applied and forms a uniform layer as it dries. Heating forms a defect-free coating of inert polymer.

Process description and development. A new process for making aqueous dispersions from bulk polyethylene now makes polyethylene coatings possible. Dow's proprietary Bluewave™ mechanical-dispersion process (Figure 4) transforms polyolefins from large polymer pellets into aqueous dispersions suitable for use as liquid coatings.

The engineering challenge was to develop and implement technology enabling the delivery of high-molecular-weight, semi-crystalline polyolefins in a low-viscosity liquid form. The inherent properties of polyolefins make this challenge formidable since they are not soluble in common industrial solvents. Utilizing Dow's Bluewave mechanical-dispersion process, polyolefin pellets are transformed into aqueous polyolefin dispersions with individual polymer particles of approximately 1 µm in diameter suspended in water. This material transformation is achieved through patented twin-screw extruder barrel configuration, element design and sequencing, as well as careful control of pressure and temperatures to simultaneously melt, disperse via a high-internal-phase emulsion (HIPE), and stabilize the polyolefins as a dispersion. The performance of these dispersions was optimized through careful composition and process experimentation, extensive high-throughput coating formulation work, and mapping of application spray and oven conditions to yield the final coating systems.

During scaleup, extensive process studies were required to move from research scale (25-mm extruder) to full production scale (58–97-mm extruders). Extruder operating conditions, including critical parameters, such as multiple temperature zones, injection water temperature, polymeric dispersant and neutralization strategy and subsequent dilution water, temperature and flows had to be optimized through sequential design-of-experimentation (DoE) methodology. In addition, extensive research was conducted on the screw element design, balancing the needed shear regime to generate the small particle size contrasted against the shear-induced temperature generation considerations. Optimized screw element layout design was critical to achieving the target particle size of the polymers. The particle size, in turn, is critical to application characteristics of the coating, affecting distribution and film weight of the coating in the can under a high-speed can manufacturing process.

The Bluewave mechanical dispersion is only part of the story. Specifically designed polyolefin resins were required and the formulation chemistry required optimization to make a superior can coating. A typical Canvera dispersion contains 3–5 polymers designed to achieve the correct balance of properties, including metal adhesion, chemical resistance, melting temperature, hardness and toughness, while ensuring dispersion stability.

Commercialization. Commercialized in December 2015, and ramped to full commercial production in 2016, Canvera dispersions are used to coat the inside of millions of metal containers in U.S. and European marketplaces, providing consumers with suitable alternatives to the incumbent epoxy-based system.

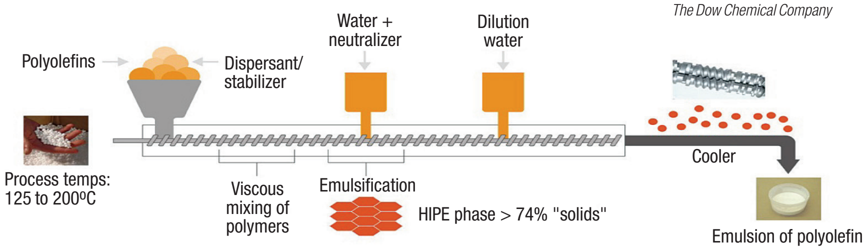


FIGURE 4. Dow's Bluewave mechanical-dispersion process transforms polyolefins from large polymer pellets into aqueous dispersions suitable for use as liquid coatings

The Dow Chemical Company: Paraloid™ Edge technology

Urethane coating resins have many desirable and a few undesirable attributes. Paraloid Edge urethane coatings are made using a completely new process that is isocyanate and formaldehyde free. Paraloid Edge resins and cross-linkers retain and add to the desirable, while eliminating some of the most undesirable attributes of urethane resins. It is a superior, not a compromised, product. Paraloid Edge resins:

- are isocyanate and formaldehyde free for safety
- provide a very fast dry time for improved productivity
- have a long pot life, reducing waste
- cure at room temperature for convenience
- are durable and weatherable
- are polyurethanes made with a better process

The final coating forms by reacting a polycarbamate and a di-aldehyde, forming a polyurethane without isocyanates. A complete redesign of the process for urethane production gives a product that is superior to conventional urethanes (Figure 5).

The Dow Chemical Company

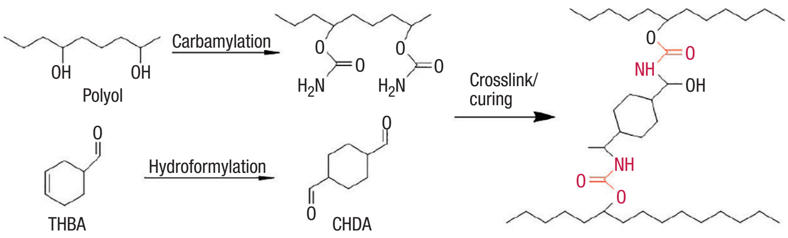


FIGURE 5. A complete redesign of the process for urethane production gives a product that is superior to conventional urethanes

Dow Coating Materials developed processes for cost-effective production of a two-part, reactive urethane coating system using polycarbamates and di-aldehydes, replacing the isocyanates and polyols used in conventional urethanes. Typical polycarbamate production uses highly toxic methyl carbamate. Dow developed processes based on urea, overcoming process challenges that hampered development of urea-based routes in the past.

Polyols polymer and polymerization design. Paraloid Edge is designed to meet or exceed the specifications met by conventional urethane coatings. These properties (solution viscosity, color, clarity, hardness, dry-time, UV resistance, chemical resistance) are essential for the successful application of the paint and the final performance of the final cured coating material. The final properties of the polymeric material are dictated by the design of its molecular structure, extensive material science and engineering R&D established structural-property relationships used to design the essential details of the polymer microstructure.

Once the polymer composition was determined, the design of the polymerization reactor system and the process conditions followed. Among the multiple engineering challenges were the following:

- Reactor temperature control due to the high heat of polymerization
- Control of molecular weight and its distribution
- Control of comonomer composition distribution

Extensive kinetics and process research and modeling was carried out to develop and optimize processes for the production of acrylic polyols.

Polycarbamates design and reaction. Polycarbamates are formed through the functionalization of reactions of polyols with urea. The carbamates are the cross-link point across the polymer chain, and therefore, the extent of the functionalization reaction essentially dictates the degree of crosslinking of the final coating material. Extensive material science and engineering R&D was carried out to determine the optimum degree of functionalization for each prototype. The optimum extent of reaction was proved to be vastly different, depending on the final application, for different prototypes, and it varied from 50% to 80% of the starting polyol hydroxyl functionality, across different prototypes.

Using urea in the carbamylation reaction introduces a number of process challenges, such as byproduct formation, low urea solubility in reaction media, and formation of hazy, highly colored product. The process developed by Dow overcomes these challenges, resulting in a very high urea conversion and producing a very clear and low-color acrylic carbamate.

Cross-linker. The di-aldehyde, cyclohexanedicarboxaldehyde (CHDA), is produced through hydroformylation of tetrahydrobenzaldehyde (THBA) with CO and H_2 in the presence of a rhodium catalyst. Two continuously stirred tank reactors (CSTRs) under pressure, in the absence of O_2, achieve >99% conversion. Process conditions, the complex operation of two CSTRs and multiple post-reaction steps, were optimized through extensive experimental and process modeling work. A proprietary process called Non-Aqueous Phase Separation, which was first commercially implemented in this technology, recovers the rhodium catalyst for reuse.

This process was first commercialized in March 2015 in the U.S.

Microvi Biotech Inc.: Denitrovi™ biocatalytic nitrate removal

Nitrate is one of the foremost drinking water challenges today, contaminating groundwater around the world and posing threats to human health. For the past ten years, Microvi has been working to provide a new solution to overcome the challenges of nitrate contamination. This technology, called Denitrovi, is based on Microvi's MicroNiche Engineering platform, where novel materials science is used to control how microorganisms behave and perform in industrial bioprocesses.

Conventional nitrate removal. Nitrate is highly mobile in groundwater and does not adsorb, volatilize or naturally degrade in the majority of groundwater aquifers. Nitrate-contaminated groundwater can be treated through two different approaches: 1) separation of nitrate (via anion exchange, reverse osmosis or nanofiltration) or 2) degradation of nitrate. The first approach is costly, energy-intensive and produces concentrated waste streams that require secondary treatment. The second approach — biological nitrate degradation (or denitrification) — is an ancient and energetically favorable microbial metabolic process that reduces nitrate to N_2. The denitrification reaction occurs under anoxic conditions, coupling nitrate (electron acceptor) to an electron donor, such as carbon or hydrogen. Nitrate degradation is an attractive alternative to separation since it does not require high energy or inherently generate concentrated waste streams. However, conventional biological denitrification technology is characterized by major disadvantages, including organism washout, slow reaction rates and sludge production.

In conventional biological denitrification treatment, the paradigm has remained the same for more than 100 years: repeatedly grow and remove the microorganisms that remove the nutrients. This fundamental paradigm imposes limitations in five key areas that govern the size and cost of biological treatment systems in general: substrate diffusion, mixing, settling, solids production and carbon consumption. Each factor contributes to low organism densities, significant sludge production and ultimately large footprints and volumes required proportionally to high hydraulic residence times (HRTs).

Denitrovi technology. Microvi is the first company to deconstruct the dominant paradigm in biological water treatment. The company's founder, Fatemeth Shirazi invented a new approach to microenvironmental engineering called MicroNiche Engineering. The MicroNiche Engineering platform is a combinatorial materials-science platform that can take nearly any kind of microorganism and using an *in silico* model, parameterize microorganism-material compositions with functionalities unachieveable using conventional techniques. Whereas conventional biological treatment technologies use various techniques to simply grow and retain biomass, MicroNiche Engineering utilizes functional cellular microenvironments that help control phenotypes, behaviors and self-organization. Denitrovi uses specially-targeted, high-performance *natural* microorganisms that are completely incorporated at very high density within material composites. These composites provide a protective microenvironment with unique geometry and physiochemical properties.

The Denitrovi technology provides a paradigm shift for translating natural microbial fitness-enhancing behaviors into an industrially relevant format. The synthetic Denitrovi biocatalysts, as a highly hydrated, hydrophillic polymer complex, mimics key fitness advantages found in natural microorganism communities while maintaining a controlled system over extended periods of time.

Using Denitrovi, nitrate-contaminated water enters a reactor and the nitrate is degraded by microorganisms housed in biocatalysts and converted into N_2. The key chemical engineering feat achieved by the technology is that it generates no sludge.

Commercialization. In January 2017, Microvi and Sunny Slope Water Company of Pasadena, Calif. launched a new, 200-million-gal/yr facility that uses Denitrovi to remove nitrate from groundwater. At Sunny Slope, the technology reduces nitrate from ~40 mg/L to <5 mg/L in a matter of minutes of contact time, while virtually eliminating the secondary waste stream that would otherwise be associated with a biological technology. Most importantly, the technology was found to be 50% of the cost of existing treatment technologies, such as ion-exchange.

Microvi Biotech Inc.

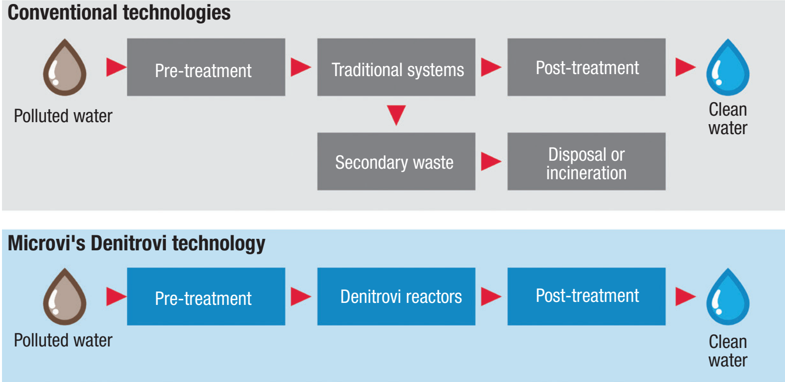


FIGURE 6. The Denitrovi process (lower) requires fewer steps than conventional biological denitrification processes (upper), without generating sludge

Praxair: Oxygen-fired combustion with thermochemical regenerators

Currently, most high-temperature furnaces still operate at net energy efficiencies below 50%, despite the many advancements made in heat-recovery technology for industrial process furnaces. The main heat loss is the sensible heat in the fluegas, due to the large fluegas volume of fuel-air combustion.

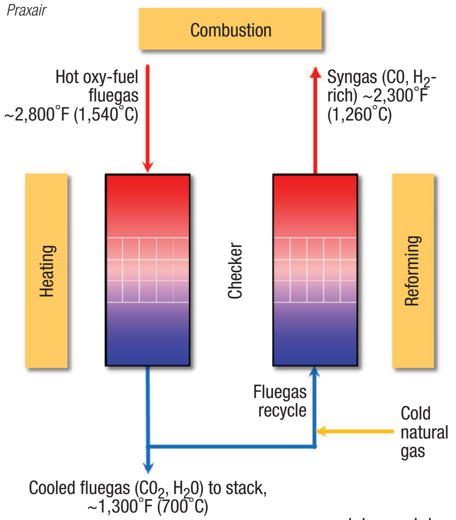


FIGURE 7. The overall concept for the Optimelt thermochemical regenerator is shown here

Increasing efficiencies. Oxy-fuel combustion eliminates N_2 that would be present using combustion air, and hence substantially reduces the fluegas volume and the sensible heat loss. For example, oxy-fuel firing reduces fuel consumption by about 30% for steel reheat furnaces equipped with metallic recuperators to preheat air. For glass melting, in furnaces equipped with efficient regenerators for waste-heat recovery, up to 10 to 15% fuel savings are achieved by oxy-fuel conversion and NOx emissions are reduced by as much as 80%.

In the U.S., about 30% of container glass furnaces have been converted to the "best available technology" for NOx control. However, less than 10% of the world's glass is produced using oxy-fuel combustion.

Metallic recuperators were recently developed to preheat both oxygen and fuel for recovering waste heat from oxy-fuel fired glass furnaces. Air is heated first by hot fluegas in a radiant-type recuperator and then the preheated air is used as the heat-transfer medium to heat both fuel and O_2 in separate recuperators. The indirect heating design addresses corrosion and fouling concerns for the heat exchangers for O_2 and fuel. The maximum O_2 preheating temperature is limited to about 600°C due to material compatibility with high-temperature O_2. The maximum natural gas preheating temperature is limited to about 450°C due to cracking of hydrocarbons and soot buildup. The maximum heat recovery efficiency is only about 24% of the sensible heat in the fluegas. Fuel savings achieved with this heat-recovery system are reported to be 8 to 9%. To date, there are only a few commercial systems installed due to the high capital cost of the system and its relatively low heat recovery efficiency.

Optimelt™ TCR. Praxair has developed a novel heat-recovery technology, the Optimelt Thermochemical Regenerator (TCR) that maximizes waste heat recovery by recovering waste heat in fluegas from oxy-fuel fired furnaces and returning the energy to the furnace as hot synthesis gas (syngas). The Optimelt TCR process (Figure 7) is the first known commercial oxy-fuel fired glass melting process utilizing endothermic chemical reactions for waste heat recovery.

During the heating cycle, waste heat from the glass furnace fluegas (about 1,540°C) is collected and stored in a regenerator. During the endothermic reforming cycle, this stored heat is used to heat and reform a mixture of natural gas and recycled fluegas to produce syngas at about 1,260°C. No catalysts are required for the reforming reactions due to the high regenerator temperature. By using two regenerators, they can alternate between heating and reforming cycles, so that one is always storing heat while the other is supplying preheated syngas to the furnace. Water vapor and CO_2 in the oxy-fuel combustion fluegas are synergistically utilized as reactants so the steam generation normally required for reforming reactions is eliminated. The syngas created from the reforming of natural gas contains hydrogen, carbon monoxide and a significant fraction of carbon (soot) particles. Soot particles are advantageous in the combustion process to produce a highly luminous flame for efficient heat transfer.

The Optimelt regenerators are similar in design to those used for conventional air heating but only require one third of the checker volume due to the reduced fluegas volume from oxy-fuel combustion, making retrofit an economically attractive option, especially when space is limited.

Commercialization. After verifying the technical feasibility, a pilot plant was constructed at the Praxair Technology center in Tonawanda, N.Y., with testing starting in 2012. The pilot scale TCR was about 1/40th of the expected size for a typical 300-ton/d commercial glass-container furnace, and utilized a natural gas flowrate for the reforming reactions of about 30 Nm^3/h.

The demonstration of the Optimelt TCR process started in a 50-ton/d container-glass furnace at Pavisa in Mexico in late 2014 (adopted for commercial operation in mid-2015). Fuel and O_2 savings of 15 to 18% and low NOx emissions were demonstrated. For a larger-scale commercial furnace, expected fuel savings are about 20% compared to oxy-fuel and about 30% compared to air-regenerator furnaces.

A larger commercial system was installed for a tableware furnace at Libbey Glass in Holland in late 2017. Application of the technology to steel and other high-temperature industrial furnaces are also being planned. ■

Edited by Gerald Ondrey

Part 2

The Road to Commercialization: Best Practices

Experts share their best practices in process commercialization

IN BRIEF

THE EARLY STAGES

DECISION POINTS

SCALEUP

STARTUP

Every day, scientists and engineers in the chemical process industries (CPI) work on innovative ideas, seeking the ones that can be turned into successful commercial products and processes. Many factors help determine which innovations progress beyond research and development (R&D) into production, and relatively few make it that far. The technologies that were awarded the 2017 winning and honoree Kirkpatrick Awards (pp. 22–28) are outstanding examples of processes that have been successfully commercialized. We have asked the experts behind these success stories to share their best practices for process commercialization with our readers. A compilation of their responses follows.

The early stages

In the initial stages of laboratory and pilot plant development, several areas were identified as being key considerations: 1) technical feasibility; 2) economics; and 3) a well-defined understanding of the end users' needs (Figure 1).

Technical feasibility. Margarete Leclerc, director of catalysis R&D for Chemetry Corp. (Moss Landing, Calif.; www.chemetrycorp.com) explains that key reaction variables, such as selectivity and yield, are studied on the laboratory scale, often using high-throughput techniques. Relevant kinetic rates are then studied on a more traditional laboratory scale. She highlights the importance of analysis, "Throughout the laboratory experiments, it is important to develop suitable analytical methods to help close material balances. Frequently, we use redundant techniques, such as gas chromatography and total organic carbon to make sure that the results are consistent across multiple analytical platforms."

Identification of raw materials is also done at an early stage. Bernhard Kainz, global technology leader packaging coatings at The Dow Chemical Company (Midland, Mich.; www.dow.com) says, "Once we identify suitable raw materials we obviously need to assess their availability — for example, whether they have already been commercialized or if they are still experimental, and how the availability may differ across regions." He also points out the need to develop techniques to test a product early on, "Lab experiments will then give a first indication of suitability, but beyond that you need to ensure you have the appropriate testing capabilities to evaluate whether developmental lab prototypes will meet performance expectations."

It is also in the early stages of development when an assessment should be made of how much a fit the overall project is for a company. Joaquim Portela, senior vice president for technology, refining and gasification at CB&I (The Woodlands, Texas; www.cbi.com) says that early on, questions such as the following are explored: "Do we have the capability in terms of resources and skill sets to complete the development? Does the product have a good fit within our overall licensing portfolio?" He also says that the potential for partnering with another company, where it makes good business sense, is considered.

Economics. Technical feasibility and economics go hand-in-hand and both are evaluated early in R&D. Hisashi (Sho) Kobayashi, senior corporate Fellow at Praxair Inc. (Danbury, Conn.; www.praxair.com), explains that "An engineering analysis and a preliminary economic analysis are conducted to check the techno-economic feasibility of an idea proposed before laboratory or pilot-scale work. Since the process economics depend on the technical performance (efficiency,

FIGURE 1. The groundwork for technical feasibility, economics and goal definition is laid in the early stages of development

yields, etc.) of the idea proposed, laboratory work is conducted to address important technical issues influencing the technical and economic feasibility."

And Kyle Self, vice president of process technology at Chemetry offers this approach to early-stage economic evaluations, "The ability to vet the economics of early stage ideas from a technical perspective is critical. Initial economic assessments should focus on opex [operating expense] advantages against competing technologies, based on a set of underlying assumptions . . . capex [capital expense] estimates are re-examined as the initial technical targets are achieved and the process flow diagram becomes clearer. The remainder of the development process is spent reducing technical risk, which is defined in terms of uncertainty in either the opex or capex calculations."

Well-defined goals. Understanding the market needs for the product or process under development, and what the requirements for the final product or process are, is a key component that should be realized early in R&D. Dow's Kainz says "For Dow Coating Materials, we not only need to have a thorough understanding of the critical requirements of the final product — i.e. it's application and final formulation — but how these requirements could translate into the properties offered by specific raw materials."

CB&I's Portela explains that a process they develop must create "compelling value" for a customer. He goes on to say that value can be defined in a number of ways. Speaking in terms of a petroleum refining customer, he elaborates, "Value can be improved profitability for the refiner relative to other process options. Value can also be looked at in terms of a refiner's ability to manufacture on-spec fuel products, which may not be possible otherwise, or to operate a unit that is inherently safer, has a smaller environmental footprint, or meets a new regulatory requirement."

Ameen Razavi, director of innovation research at Microvi Biotech Inc. (Union City, Calif.; www.microvi.com) offers the following advice, "Begin with the end in mind! Without a clear, quantifiable understanding of the eventual application, misdirection in the development or commercialization process becomes more likely."

Decision points

Almost all of the experts use stage-gating procedures within their companies to make decisions along the developmental path. These well-defined decision points typically involve technical, economic and market checks. Potential regulatory issues, where applicable, were also cited as part of the check. In some cases, direct customer feedback is sought.

Microvi's Razavi agrees that re-evaluations are necessary, but he takes a different approach, which uses milestones for evaluations rather than a fixed stage-gating procedure. He defines a factor called "level of confidence," which "is one of the considerations we use in holistically analyzing whether a project should continue or not."

Scaleup

During the scaleup phase of development, numerous challenges to the development may be confronted and need to be resolved. Often, these challenges are encountered in the pilot-plant (Figure 2). Additional laboratory testing may be required to resolve issues, such as those caused by raw material variations. Understanding basic chemical

engineering principles is vital, as Chemetry's Self points out: "Chemical engineers understand that scaleup challenges typically result from issues related to the interplay between heat transfer, mass transfer and reactor kinetics. Successful scaleup typically depends on the extent those effects are understood and minimized before transitioning to the next scale."

A number of our interviewees described a traditional scaleup procedure, moving from small scale through a bench or pilot stage to a commercial development scale. Randy Seeker, chief technology officer at Chemetry advises to "include at least a year of pilot plant work in the plan — rushing to demo/commercial scale before completing pilot testing will result in expensive modifications at the demo scale."

Pilot plant testing can be expensive, and as Praxair's Kobayashi highlights, "The cost of pilot-scale work increases sharply with the scale of the pilot system and the decision on what scale to choose is important. We conduct pilot scale tests at the smallest scale possible to represent the commercial-scale process and generate process data." He further points out the value of computational fluid dynamic (CFD) models using the data from the pilot tests.

Chemetry's Self affirms the usefulness of CFD models, "When executed properly, CFD modeling is an investment in development that can pay off in multiples at the demonstration scale and beyond." Self also stresses that more specialized unit operations, such as electrochemical cells, require particularly careful attention during scaleup.

FIGURE 2. Hurdles in process development are often addressed on the pilot-plant and demonstration scales

Startup

Not unlike the pilot-plant phase, it is common to encounter hurdles during startup. One of the key factors to successful startups cited by the experts is thorough and early planning. And the planning needs to encompass all aspects of the process — for example, written and reviewed standard operating procedures, operator training, analytical support, early contracting for raw material supplies, storage and logistics, worked-out production schedules, safety reviews and more.

Good communication is a vital part of this startup planning, and throughout process development. There are many disciplines involved with commercializing a process, including laboratory scientists, pilot-plant engineers, manufacturing engineers, analytical scientists, safety specialists, procurement professionals, contractors, regulatory and applications experts. Input from all relevant disciplines needs to be shared and considered. Our experts have cited the use of internal documents, team meetings and coordination by a project leader as key methods for keeping communication flowing. Special consideration has to be given to language when barriers exist, such as can occur in international developments.

The road to process commercialization, particularly those involving new, breakthrough technologies, can be long and difficult with unexpected turns along the way. Technical and economic factors need to be considered at the outset, and good project management is needed for execution. CB&I's Portela advises: "Breakthrough developments, by nature, take longer to commercialize and may be more costly when compared to incremental process improvements, hence we must be patient for the development process to play out. These are the developments that overcome difficult chemical engineering problems and require innovative solutions, persistence and teamwork." ■

Dorothy Lozowski

ACKNOWLEDGEMENTS

Thank you to the teams representing the six 2017 Kirkpatrick Award winner and honorees for their input about process commercialization, which is summarized in this article.

High-Shear Mixing

Department Editor: Scott Jenkins

High-shear, high-speed mixing equipment supplies the mechanical energy necessary to reduce the size of solid particles and liquid droplets in emulsions and dispersions. Emulsions are mixtures of two normally immiscible liquids in which tiny particles of one liquid are suspended in another. Dispersions refer to solid particles distributed uniformly throughout a continuous medium. High-shear mixing processes are common across the chemical process industries (CPI), including in foods, cosmetics, pharmaceuticals, greases and lubricants, specialty chemicals, paints, inks and others. This one-page reference provides information on high-shear mixing operations and equipment.

Rotor-stator mixers

Rotor-stator mixers are standard workhorses used throughout the CPI for preparing fine dispersions and emulsions. The traditional design features a four-blade rotor running at tip speeds in the range of 3,000–4,000 ft/min within a close-tolerance fixed stator. The mixer creates mechanical and hydraulic shear by continuously drawing product components into the rotor and expelling them radially through the openings in the stator. Rotor-stator mixing devices are offered in both batch and inline configurations. Multi-stage designs are also available. These typically consist of 2–4 rows of teeth, and run at the same maximum tip speeds as their single-stage counterparts.

Particle size profile

Any high-shear, high-speed mixing operation — whether the process goal is powder dispersion, deagglomeration or emulsification — generates a Gaussian distribution of particle size. The objective is usually to produce the narrowest distribution possible with equipment that meets both process and business needs. In some applications, quality control is generally concerned with average particle size, while others follow strict standards pertaining to the largest diameter particles permitted in a suspension. Particle size profile is just one of many indicators of a good product. Depending on the end use, other properties like conductivity, stability, viscosity, color, gloss and so on, whether directly or indirectly related to particle size, are also considered during equipment testing and selection.

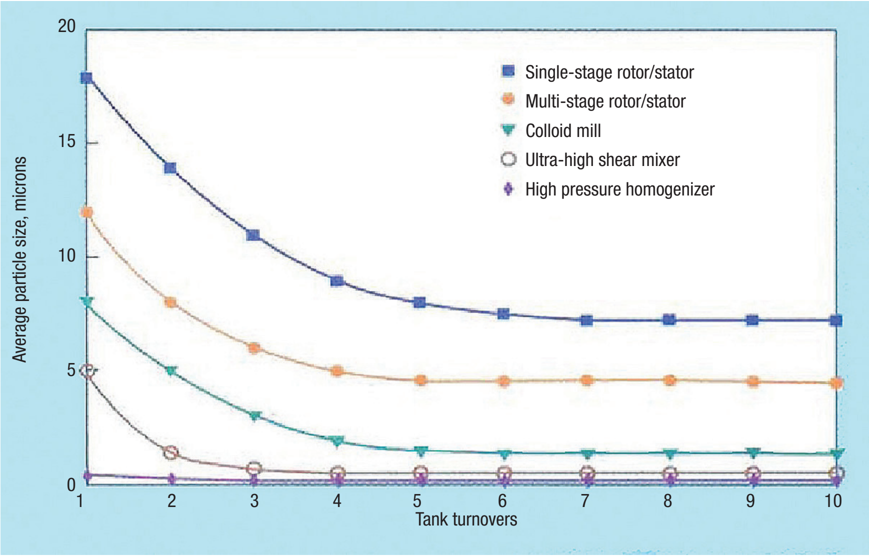


FIGURE 1. Various technologies can achieve different particle sizes (particle fineness) in emulsions

Particle size equilibrium

The majority of particle or droplet size reduction occurs within the first few passes through an inline mixer, or the first few tank turnovers in a batch mixer. This phenomenon is true for almost any dispersion or emulsion. Past this stage of sharp decrease in particle size, the distribution hovers at an equilibrium (see Figure). Additional processing will gradually narrow the distribution curve, but extending the process for this purpose alone is almost always unprofitable. If the equilibrium particle or droplet size achieved in a single-stage or multi-stage rotor-stator is larger than desired, manufacturers are often forced to use more expensive, higher-energy devices, such as high-pressure homogenizers and colloid mills.

In a high-pressure homogenizer, the fluid is subjected to very high shear stress as it is forced through a specially designed homogenization nozzle at pressures of 150–200 MPa. However, high-pressure homogenizers, colloid mills (which also work on a rotor-stator principle) and similar equipment are commonly associated with several drawbacks, including higher capital cost and lower throughput than mixing technologies, along with frequent clogging, labor-intensive cleaning and high maintenance requirements.

Ultra-high shear

Among the recent developments in mixing are more cost-effective rotor-stator designs capable of delivering intense mixing along with rugged efficiency. Ultra-high-shear mixers offer the ability produce dispersions and emulsions superior to those made in multi-stage rotor-stators and colloid mills. In certain applications, these can replace high-pressure homogenizers, delivering comparable size reduction at significantly higher throughputs.

Ultra-high-shear mixers do not eliminate the premixing process — the feed must be a dispersion or emulsion in liquid form. Simple to operate, much like a regular inline rotor-stator mixer, these behave like a centrifugal pumping device. Materials are fed by gravity or pumped to the mixer. With the assistance of an auxiliary pump, ultra-high-shear mixers can process non-flowing, viscous materials like gels, pastes and creams. ■

Editor's note: Material in this month's column was contributed by Christine Banaszek, Charles Ross & Son Co. (Hauppauge, N.Y.; www.mixers.com).

Activated Carbon Production

By Intratec Solutions

Activated carbon, also known as activated charcoal or activated coal, is an inert solid composed mostly of carbon atoms, processed to have porous structure and a large internal surface area. These unique characteristics impart adsorptive properties that make activated carbon attractive for use in a range of liquid- and gas-phase applications.

The process

The following paragraphs describe activated carbon production from coconut shells, which involves two main steps: carbonization of coconut shells into shell charcoal, followed by steam activation at high temperatures. Figure 1 presents a simplified flow diagram of the process.

Carbonization. Initially, coconut shells are fed to a crusher, where the size of the shells are reduced. The crushed material is fed to a flash dryer to remove moisture, and then fed to a rotary kiln to be carbonized. The shell fragments are heated under nitrogen in such a way that non-carbonaceous material — elements such as hydrogen and oxygen — is volatilized and eliminated from the precursor. Carbonization produces charcoal, with bio-oil vapors, steam and incondensable gases as byproducts. At this point, a carbon skeleton possessing a latent pore structure is formed. Oils and tars separated as byproduct are used for fuel.

Steam activation. In a fluidized-bed reactor, the charcoal is activated by reaction with steam at a temperature of 900–1,100°C under controlled atmosphere. The activation promotes the elimination of volatile components and the simultaneous oxidation of the outer surface of the charcoal, forming active sites. The gas escapes from the charcoal, leaving behind pores in the carbon solid. Air is also fed to the reactor, for the combustion of the carbon monoxide and hydrogen formed during activation. Carbon monoxide and H_2 are converted to steam and carbon dioxide.

Then the activated carbon undergoes a sequence of steps in which it is cooled and ground to the desired particle size. The activated carbon is cooled to ambient temperature by indirect cooling, and then ground into powder of specified mesh size. At this point, the finished powdered activated carbon is directed to a packing system.

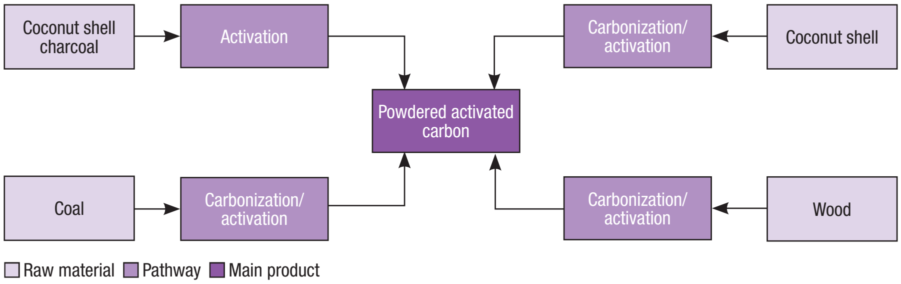


FIGURE 2. The diagram shows several possible production pathways for activated carbon

Production pathways

Activated carbon can be produced from several carbon-rich raw materials, such as coal, lignite, wood, pitches and agricultural and forestry wastes. When it comes to manufacturing processes, there are basically two main activation methods: chemical activation, based on the dehydrating action of chemicals; and physical activation, based on the use of gases, such as steam or carbon dioxide. Several different pathways for activated carbon are presented in Figure 2.

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce activated carbon was about $2,400 per ton of activated carbon in the first quarter of 2014. The analysis was based on a plant constructed in the U.S. with capacity to produce 10,000 metric ton per year of activated carbon.

This column is based on “Activated Carbon Production Process – Cost Analysis,” a report published by Intratec. It can be found at: www.intratec.us/analysis/activated-carbon-production-cost. ■

Edited by Scott Jenkins

Editor's note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering.* The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

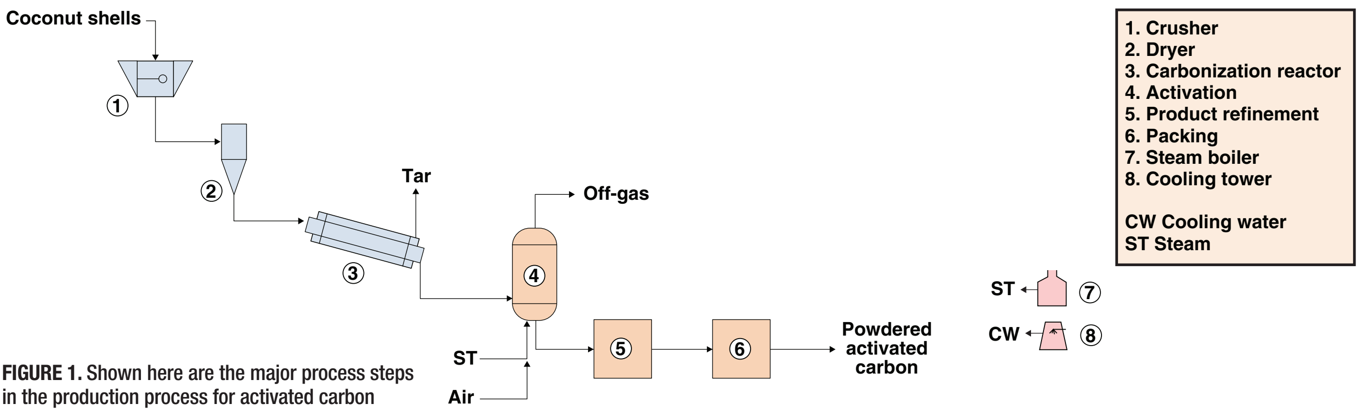


FIGURE 1. Shown here are the major process steps in the production process for activated carbon

Pump Sizing and Selection Made Easy

Viscosity, power consumption, commercial availability and lifecyle cost analysis are all important considerations in pump sizing. An automated spreadsheet method helps engineers take those factors into account in centrifugal pump selection

Joseph Sarver, Blake Finkenauer and Y.A. Liu
Virginia Polytechnic Institute and State University

IN BRIEF

Many aspiring chemical engineers enter industry after university study without sufficient practical knowledge about how to properly size pumps. A number of recent articles provide useful guidelines for sizing and selecting pumps, but these articles focus on certain specific aspects of proper pump sizing, while leaving out others [*1–4*]. Chemical engineering literature does not fully cover other essential aspects of pump sizing and selection — including the viscosity correction, power consumption, commercial availability and lifecycle cost analysis.

In industrial operations, pumping alone can account for between 25 and 50% of the total energy usage of the process, depending on the application [*5*]. The initial purchase price of a pump is only a small fraction of the total lifecycle cost. There are situations in which purchasing a less expensive pump actually leads to greater energy-usage costs. This results in a higher lifecycle cost (see Example 1, p. 36).

Without a proper understanding of the pump selection process, engineers cannot effectively make both economic and practical decisions. This article aims to fill in some of the gaps in understanding and provide a straightforward method for pump sizing and selection. Along with this article, we have created a useful Microsoft Excel spreadsheet to assist with centrifugal pump sizing. The automated Excel spreadsheet assists in calculating the key parameters for pump sizing and selection. Since the majority of the pumps used in the chemical process industries (CPI) are centrifugal pumps, this article focuses on that equipment category, rather than the other general classes of pumps, such as rotary and positive displacement pumps.

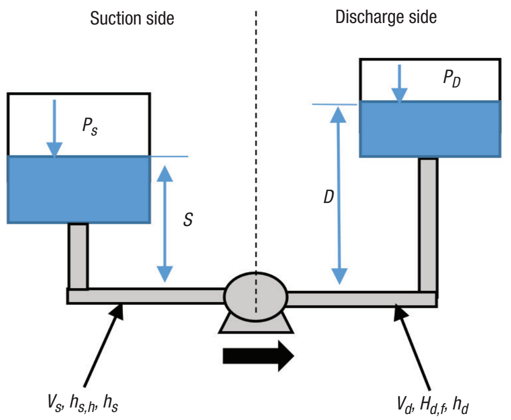


FIGURE 1. The following components are needed to calculate total dynamic head: suction and discharge elevation; fluid velocity; friction loss and dynamic head; and tank pressure

Pump sizing overview

The concept of a pumping system is rather simple. The suction side refers to everything before the pump, while the discharge side refers to everything after the pump. Figure 1 illustrates a simplified pumping system. A key parameter in characterizing a pump is the total dynamic head (TDH), which is the difference between the dynamic pressure of the discharge side and the suction side. The dynamic pressure represents the energy required to do the following: (1) to raise the liquid level from the suction tank to the discharge tank; (2) to provide liquid velocity inside both suction and discharge piping; (3) to overcome frictional losses in both suction and discharge piping; and (4) to pump the liquid against the pressure difference between the suction and discharge tanks.

Six steps to pump sizing. In order to size a pump, engineers need to estimate the temperature, density, viscosity and vapor pressure of the fluid being pumped. Pump sizing can be accomplished in six steps, as follows:

1. Find the total dynamic head, which is a

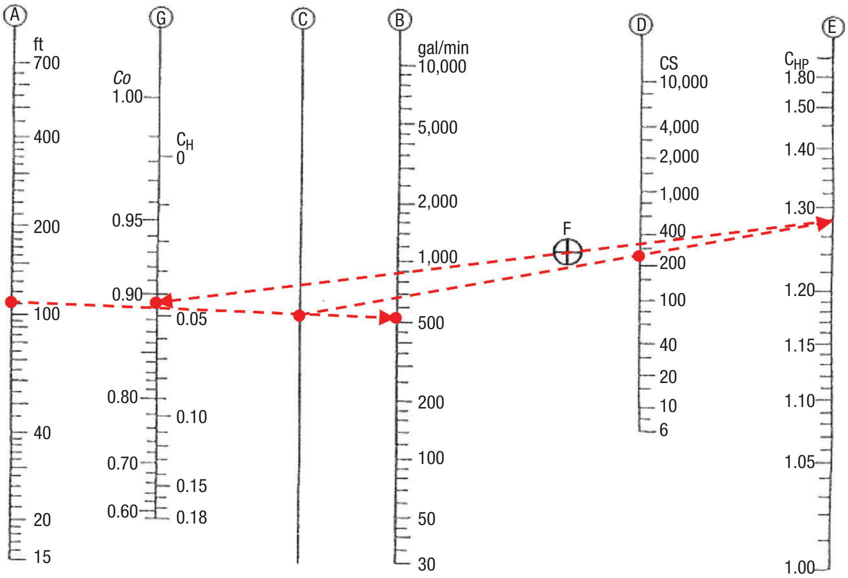


FIGURE 2. Shown here is a viscosity correction chart. The red dashed line corresponds to Example 2 on p. 40

function of the four key components of a pumping system, such as the one shown in Figure 1

2. Correct for the viscosity of the fluid being pumped, since pump charts and data are given for water with a viscosity of 1 cP. The viscosity of other process fluids can differ dramatically
3. Calculate the net positive suction head (NPSH) to select a pump that will not undergo cavitation
4. Check the value of suction-specific speed to see if a commercial pump is readily available (see section on suction-specific speed later in this article)
5. Check for potentially suitable pumps using a composite performance curve and an individual pump performance curve
6. Compare the energy consumption and lifecycle cost of operating the selected pumps

Calculating friction losses

Pumps must overcome the frictional losses of the fluid in order for the fluid to flow in the suction and discharge lines. These frictional losses depend on pipe roughness, valves, fittings, pipe contractions, enlargements, pipe length, flowrate and liquid viscosity.

To calculate the frictional head losses, in feet of liquid being pumped, on the suction ($h_{s,f}$) and discharge ($h_{d,f}$) side of the pump, Equation (1) can be used. The same equation can be applied to calculate the frictional losses of the discharge side, but with the appropriate values

EXAMPLE 1. PUMP SIZING AND SELECTION

The following is a pump sizing problem to illustrate the calculations in this article. You are told to purchase a pump for your manufacturing facility that will carry water to the top of a tower at your facility. The pump is a centrifugal pump that will need to pump 800 gal/min when in normal operation. Assume BHP is 32 and 16 horsepower for the 3,500-rpm and 2,850-rpm pumps, respectively, for all pump choices in the composite curve. The pump operates for 8,000 h/yr. Assume all of the pumps are viable for your required flowrate. The suction-side pipe and discharge-side pipe diameters are 4 and 3 in., respectively. The suction tank elevation (*S*) is 12 ft, and the discharge tank elevation (*D*) is 150 ft. Pressure on the suction side is atmospheric pressure (1 atm = 14.696 psi) and the pressure on the discharge side is 1.1 atm. Assume that both $h_{d,f}$ and $h_{s,f}$ are roughly 10 ft.

Based on a five-year life, the objective of the problem is to calculate the lifecycle cost to operate each pump (that is, the costs of installation, maintenance and electricity, which is $0.18/kW), and to choose the pump with the lowest lifecycle cost (depreciation is assumed to be negligible for this example). The pump curves in Figure 3 illustrate the following pump options to choose.

Option 1: 4 X 3 – 13 3,500 rpm
Installed cost of pump and motor: $20,000 for 3,500 rpm
Maintenance cost: 10% of installed cost per year
Motor efficiency: 65% (assumed)

Option 2: 4 X 3 – 13 2,850 rpm
Installed cost of pump and motor: $40,000 for 2,850 rpm
Maintenance cost: 8% of installed cost per year
Motor efficiency: 80% (assumed)

Option 3: 4 X 3 – 10 3,500 rpm
Installed cost of pump and motor: $10,000 for 3,500 rpm
Maintenance cost: 10% of installed cost per year
Motor efficiency: 65% (assumed)

Option 4: 4 X 3 – 10 2,850 rpm
Installed cost of pump and motor: $20,000 for 2,850 rpm
Maintenance Cost: 8% of installed cost per year
Motor Efficiency: 80% (assumed)

Solution:
Convert volumetric flow to velocity:

$$Flow\ rate\ \left(\frac{gallons}{minute}\right)\cdot\frac{1\ ft^3}{448.83\ gpm}(conversion)\cdot\frac{1}{pipe\ area\ (ft^2)}\cdot\frac{1\ minute}{60\ seconds}$$

$$Suction\ Side\ Velocity{:}\ 800\ gpm\ \cdot\frac{1\ ft^3}{448.83\ gpm}\cdot\frac{1}{\left(\frac{2}{12}\right)^2\pi}\cdot\frac{1}{60}=0.340\ ft/s$$

$$Discharge\ Side\ Velocity{:}\ 800\ gpm\ \cdot\frac{1\ ft^3}{448.83\ gpm}\cdot\frac{1}{\left(\frac{1.5}{12}\right)^2\pi}\cdot\frac{1}{60}=0.605\ ft/s$$

$$h_d=D+\frac{v_d^2}{2\times g}+h_{d,f}+P_d$$

$$h_d=150ft+\frac{(0.605\ \frac{ft}{s})^2}{2\times 32.2\ \frac{ft}{s^2}}+10ft+\ 16.166\ psi\times\frac{2.31}{1.0}\ (ft)$$

$$h_s=S-\frac{v_s^2}{2\times g}-h_{s,f}+P_s$$

$$h_s=12\ ft+\frac{(0.340\ \frac{ft}{s})^2}{2\times 32.2\ \frac{ft}{s^2}}+10+\ 14.696\ psi\times\frac{2.31}{1.0}\ (ft)$$

$$TDH=h_D-h_S$$

$$TDH=153\ \text{ft}$$

Continued on page 37

correlating to the discharge side of the pump.

$$h_{s,f}=12\times f_D\left(\frac{L}{I.D.}\right)\times\left(\frac{v^2}{2\times g}\right)+\frac{v^2}{2\times g}\sum_i^N(n_i\times k_i)\quad\textbf{(1)}$$

In the equation, f_D is the Darcy friction factor, *L* is the pipe length in feet, *I.D.* is the inner pipe diameter in inches, *v* is the average fluid velocity in ft/s, *g* is the acceleration due to gravity in ft/s^2, n_i is the *i*-th valve, fitting, pipe contraction and enlargement and so on, and k_i is the resistance coefficient.

The first term in Equation (1) represents the frictional losses from the fluid flowing through a straight piece of pipe. The second term represents the frictional losses due to valves, fittings, pipe contractions and enlargements. We have provided the values for the typical resistance coefficients and pipe surface roughness from the chemical engineering literature in the Excel spreadsheet discussed in this article.

A control valve follows the widely accepted heuristic of having a fric-

PUMP SIZING AND SELECTION EXAMPLE 1 (CONTINUED)

From looking at the TDH and Figure 3, the choice is between Option 1 and Option 2. Notice that most of the TDH comes from the significant elevation difference between the suction and discharge side. Now that two pumps are feasible from the perspective of TDH requirements, you can compare the economics. At first glance, it is tempting to choose Option 1, since the initial investment is significantly lower. Although Option 2 has a higher initial cost, the lifetime cost over five years is dramatically lower. The problem shows that, in selecting a pump, the costs associated with power consumption and maintenance are critical pieces of information for making an informed decision.

$$Power\ [kW] = \left(\frac{BHP}{E_m}\right)\cdot\ 0.7457\ \frac{kW}{hP}$$

$$Power\ [kW](Option\ 1) = \left(\frac{BHP}{E_m}\right)\cdot\ 0.7457\ \frac{kW}{hP} = \left(\frac{32}{0.65}\right)\cdot\ 0.7457 = 36.71\ kW$$

$$Power\ [kW](Option\ 2) = \left(\frac{BHP}{E_m}\right)\cdot\ 0.7457\ \frac{kW}{hP} = \left(\frac{16}{0.80}\right)\cdot\ 0.7457 = 14.914\ kW$$

$$Cost[\$] = (Power)\cdot(Operating\ Hours)\cdot\left(\frac{Cost}{kWH}\right)$$

$$Cost[\$] = (36.71kW)\cdot(8000\ hours)\cdot\left(\frac{\$0.18}{kWH}\right) = \$52{,}862$$

$$Cost[\$] = (14.914\ kW)\cdot(8000\ hours)\cdot\left(\frac{\$0.18}{kWH}\right) = \$21{,}476$$

Year	Option 1			Option 2		
Cost	Purchasing	Maintenance	Electricity	Purchasing	Maintenance	Electricity
0	20,000			40,000		
1		2,000	52,862		3,200	21,476
2		2,000	52,862		3,200	21,476
3		2,000	52,862		3,200	21,476
4		2,000	52,862		3,200	21,476
5		2,000	52,862		3,200	21,476
	Total cost		$294,310	Total cost		$163,380

tion head loss of 25% of the total calculated friction head loss on the suction or discharge line where the valve is located [4]. An illustration of this solution can be observed in Example 2 on page 40. We also implement the same heuristic within the Excel spreadsheet.

The Darcy friction factor f_D can be calculated using the Churchill equation, Equation (2), which is applicable for all values of Reynolds number (*Re*).

$$8\times\left[\left(\frac{8}{Re}\right)^{12}+\frac{1}{(A+B)^{\frac{3}{2}}}\right]^{\frac{1}{12}} \qquad f_d =$$

$$\ln\left(\frac{1}{\left(\frac{7}{Re}\right)^{0.9}+0.27\times\frac{\varepsilon}{D}}\right)\Bigg]^{16} \qquad A = \Bigg[2.457\times$$

$$16 \qquad B = \left(\frac{37530}{Re}\right) \tag{2}$$

In the equation, *Re* is the Reynolds number and ε/D is the dimensionless ratio of surface roughness to pipe inner diameter. The equation for the Reynolds number of a circular pipe appears in Equation 3.

$$e = \rho vD/\mu h \tag{3}$$

In the equation, μ is the fluid viscosity, ρ is the fluid density, D is the pipe inner diameter, and v is the average fluid velocity.

A useful heuristic is to add a 15% safety factor to reduce the chance of underestimating the calculated frictional head losses. Sample calculations using these equations appear in the examples within this article.

Calculating total dynamic head

To find the total dynamic head, the difference between the discharge velocity head (h_D) and the suction velocity head (h_s) needs to be calculated.

$$DH = h_D - h_s \tag{4}$$

$$= D + \frac{v_d^2}{2\times g} + h_{d,f} + P_d h_d \tag{5}$$

$$= S - \frac{v_s^2}{2\times g} - h_{s,f} + P_s h_s \tag{6}$$

$$(ft) = P(psi)\times\frac{2.31}{sp.gr.}P \tag{7}$$

The total dynamic head depends on the elevation difference between the discharge tank and suction tank (Figure 1). In Equations (5) and (6), P is the pressure of the suction or discharge side converted to units of length using the specific gravity of the fluid as in Equation (7). The TDH represents the difference between Equations (5) and (6), in which users actually add together the velocity head and the frictional head loss for both the suction and discharge sides of the pump.

Net positive suction head

NPSH is used in the determination of whether the liquid on the suction side of the selected pump will vaporize at the pumping temperature, thus causing cavitation and rendering the pump inoperable. NPSH varies with impeller speed and flowrate.

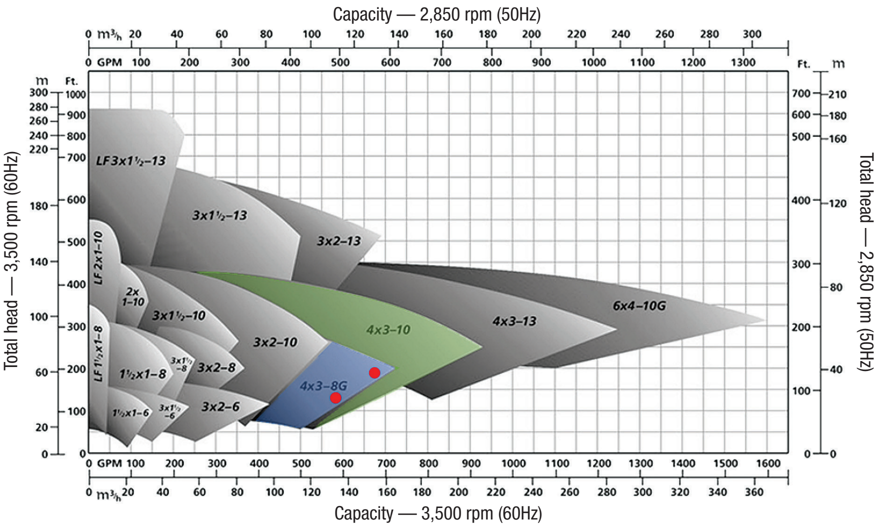


FIGURE 3. These pump composite curves show the options for Examples 1 and 2

$$NPSH_a(ft) = h_s - P_{vp}(ft) - \frac{v_s^2}{2g} - h_{s,f} + [P_s - P_{vp}](psi) \times 2.31/(sp.gr.) \quad (8)$$

To prevent cavitation in a pumping system, $NPSH_a$ should be at least 3 ft above the required NPSH value (denoted by $NPSH_r$) read from the pump curve for the given TDH and pumping rate.

$$NPSH_a \geq NPSH_r + 3\,ft \quad (9)$$

Based on Equation (8), there are several ways to increase the $NPSH_a$ to make a pumping system feasible. They include the following:

1. Raise the liquid level in the suction tank (increasing the S term)
2. Lowering the pump location (increasing the S term)
3. Reducing the frictional loss on the suction side (by reducing suction side velocity or pipe length)
4. Pressurizing the suction tank (increase P_s)
5. Lower vapor pressure by reducing pumping temperature (reduce P_{vp})

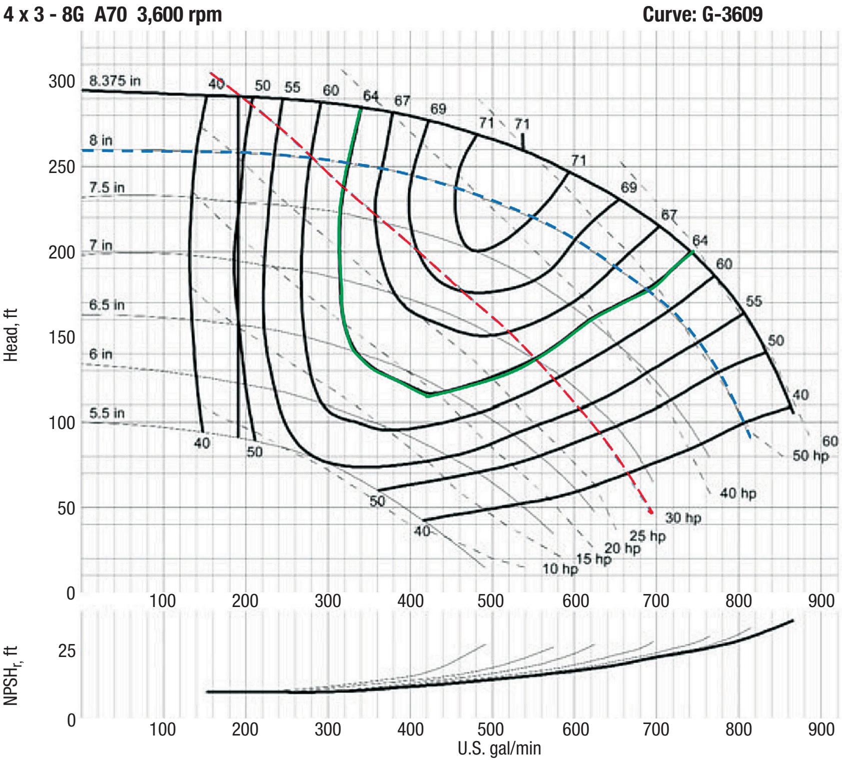


FIGURE 4. This individual pump performance illustrates Example 2, p. 40

Viscosity and pump sizing

Viscosity correction is often overlooked in pump sizing by new engineers. As stated previously, all pump curves are drawn for water with a viscosity of 1 cP. Therefore, we need to pay attention to viscosity corrections to pump performance. The Durion Co. Inc., now a part of Flowserve Corp. (Irving, Tex.; www.flowserve.com), has released a simple graphical approach. Head and capacity are not noticeably changed by viscosity below 4.3 cP at pumping temperature. Pump efficiency is reduced when handling liquids with viscosity over 4.3 cP at pumping temperature. Using a fluid with a higher or lower viscosity compared to water changes the dynamics of the centrifugal pump. Power consumption increases rapidly with a viscosity increase because of reduced efficiency. In order to select a pump from standard performance curves, it is necessary to apply correction factors to determine the equivalent pumping rate and total dynamic head for water before reading the pump curves.

The graphical approach utilizes straight lines to determine simple correction factors for the horsepower, capacity and total dynamic head. First, convert the viscosity units to centistokes (CS) by dividing the centipoise (cP) value by the specific gravity. Referring to Figure 2, start by drawing a straight line from the calculated total dynamic head (A) to the flowrate (B). Then, draw a straight line from the intersection on line C through the known viscosity in centistokes (D) until reaching line E. From line E, one can read the correction factor for break horsepower (C_{hp}). From the intersection on line E, draw a line through point F to line G, where the correction factors for flowrate (C_Q) and total dynamic head (C_H) can be read. We have automated this process in the Excel spreadsheet.

After obtaining the correction factors, Equations (9), (10) and (11) can be used to correct brake horsepower (BHP) capacity and total dynamic head (TDH). Specifically, input the values for the viscous liquid, use the correction factors read from the chart, and calculate the equivalent

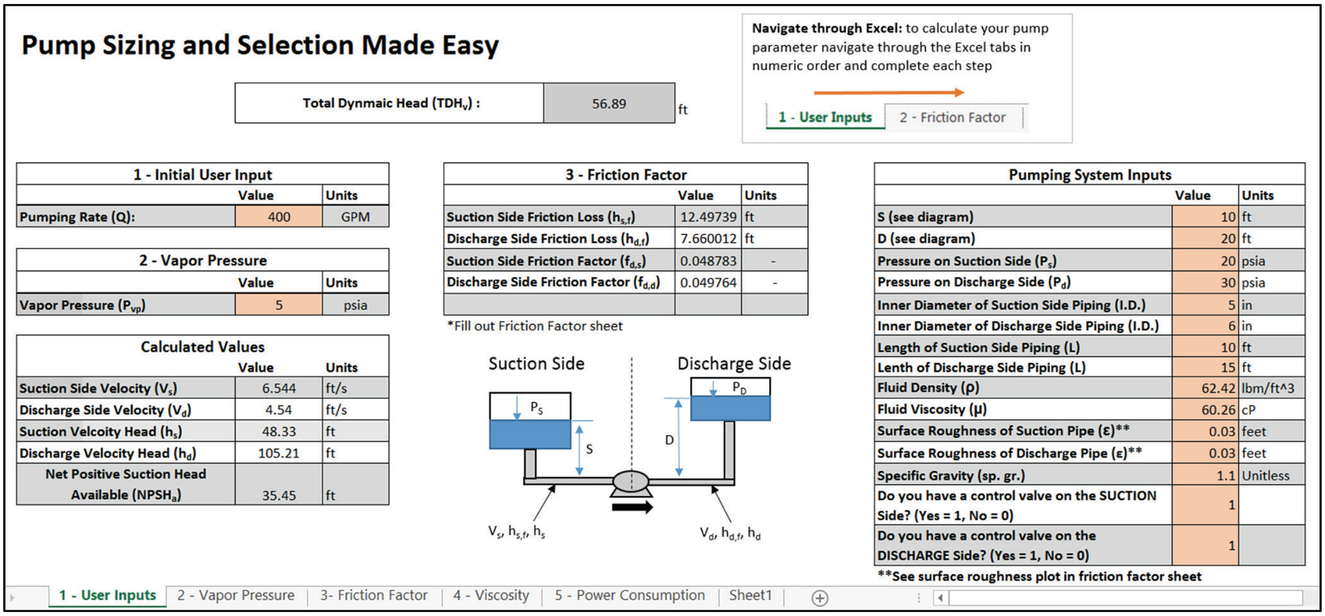


FIGURE 5. This shows the home screen of the automated Excel spreadsheet. It can be downloaded at this URL: http://design.che.vt.edu/

water values (especially TDH_{water} and Q_{water}) for use in reading pump curves. In Equation (10), assume that the water capacity is at the best efficiency point.

$$BHP_{viscous} = BHP_{water} \times C_{HP} \times$$ specific gravity/s (9)

$$TDH_{viscous} = TDH_{water} \times (1 - C_H)\ 1. \tag{10}$$

$$Q_{viscous} = Q_{water} \times C_Q. \tag{11}$$

Pump curves

Figure 3 shows a pump composite curve from Griswold Pump Co. (Grand Terrace, Calif.; www.psgdover.com/griswold). Use the pump composite curves to select an appropriate pump for the vis-

PUMP SELECTION, EXAMPLE 2

An additional pump selection problem is shown Example 2. For this example, consider a discharge line that is 50 ft schedule 40, 4-in. diameter, with two gate valves, 12 elbows, 1 expander (2–4 in.), a control valve, and a branched tee. The velocity is 12.84 ft/s, Reynolds number is 1,601, and the Darcy friction factor is 0.119. The elevation difference on the discharge side is 17 ft, the total dynamic suction head is 50 ft, and the pressure on the discharge side is 14.696 psi. The objectives in this example are to accomplish the following: 1) Calculate the discharge frictional head loss and total dynamic head; 2) Correct for viscosity of the fluid, which is 300 cP at 125°C; and 3) select an appropriate pump from Figure 3; and 4) Ensure that cavitation is not an issue with the selected pump given the vapor pressure is 13.93 mm Hg and specific gravity is 1.20.

Solution: For choosing the appropriate pump, see Figures 3 and 4. Notice on the pump composite curve, the 4 x 3 – 10 section is very close to the 4 x 3-8G. Both pumps should be analyzed by performing a lifecycle cost analysis using the pump efficiencies from the individual pump performance curves.

$$h_{d,f} = \left[\left(12\frac{in}{ft}\right)\times(0.119)\times\frac{50\ ft}{4.026\ in} + 2\times0.136 + 12\times0.21 + 0.68 + 6.06\right]\times\frac{\left(12.84\frac{ft}{s}\right)^2}{\left(2\times32.174\frac{ft}{s^2}\right)}$$

$$h_{d,f} = 69.86\ ft$$

$$\frac{1}{4} = \frac{x}{69.86\ ft + x} \rightarrow x = 23.29\ ft \ \text{(friction head loss across valve)}$$

$$15\%\ safety\ factor \qquad h_{d,f} = (69.86 + 23.29) * 1.15 = 107.1 ft$$

TDH = $h_d - h_s$

$$P_d = 14.696\ psi * 2.31\frac{ft}{psi} * \frac{1}{0.987\ (specific\ gravity)} = 34.39\ ft$$

$$h_d = 17\ ft + 107 ft + \frac{\left(12.84\frac{ft}{s}\right)^2}{2*32.174\ ft/s^2} + 34.39\ ft = 161\ ft \qquad TDH_{visc} = 161\ ft - 50\ ft = 111\ ft$$

$$CS = 300\ cP/1.20 = 250 \qquad \text{Using Viscosity Correction Chart: } C_Q = 0.89, C_H = 0.045\ \text{(Figure 2)}$$

$$TDH_w = \frac{(111\ ft)}{1 - 0.045} = 116\ ft \qquad Q_w = \frac{509\ GPM}{0.89} = 572\ GPM$$

$$NPSH_a = h_s - P_{vp} = 50\ ft - 13.93\ mmHg \times \frac{14.696\ psi}{760\ mmHg}\times\frac{1}{1.20}\times 2.31\frac{ft}{psi} = 49.5\ ft$$

Our $NPSH_a$ is much greater than the $NPSH_r$ and thus should avoid cavitation under normal operating conditions.

cosity-corrected TDH and pumping capacity. The *y*-axis of the graph is the equivalent water TDH. The *x*-axis of the graph is the equivalent water volumetric flowrate. Figure 3 has multiple shaded sections, with each corresponding to a different-sized pump. In the individual sections, the pumps are specified by the suction pipe diameter, discharge pipe diameter, and impeller size (4 × 3 – 8G for our selected pump in Example 2). Remember that the larger pipe diameter is always the suction side. For this pump composite curve, there are two *x*-axes for different impeller speeds. Notice that the two red points both correspond to 570 gal/min of flow and 110 ft of TDH for the different impeller speeds (2,850 and 3,500 rpm). The point that corresponds to this TDH and flowrate may not be the pump that is ultimately selected. For example, if the point is close to the boundary, engineers would need to move vertically up on the composite curve and choose a pump with a larger impeller size (4 × 3 – 10 versus 4 × 3 – 8G). It is very important to always compare the lifecycle cost for the different pumps (see Example 1 on p. 36).

After looking at the pump composite curve and selecting potential pumps, the next step is to look at the individual pump performance curves to obtain the pump efficiency, $NPSH_r$, and impeller size. Figure 4 is an example of an individual pump performance curve. The required NPSH is located at the bottom of this figure, separate from the rest of the performance curve. Keep in mind that not all pump curves are the same and vary by manufacturer. In Figure 4, the blue curve is for an 8-in. impeller diameter. The green curve is for a pump efficiency of 64% and the red curve is for 30 BHP. In most pump curves, engineers could not read the BHP accurately; so instead, we recommend calculating the BHP manually using the pump efficiency according to Equation (12) below.

Power and efficiency

Brake horsepower (BHP) is the actual horsepower delivered to the pump shaft. To find the BHP for a viscous liquid (BHP_{vis}), use Equation (9), after calculating the break horsepower for the equivalent water values (BHP_W, TDH_{water} and Q_{water}) and efficiency ($\varepsilon_{p,W}$) from the pump curve using Equation (12).

$$BHP_W = \frac{Q_W \cdot TDH_W}{3960 \cdot \varepsilon_{p,W}} \tag{12}$$

To determine the electricity cost for operating the pump, use Equations (13), (14) and (15). Equation (13) converts the BHP of your pump to the input power or electricity consumption. Determining the power

consumption involves the motor efficiency (E_m), which can be obtained from the vendor or estimated from the BHP using the Peter and Timmerhaus correlation, Equation (15) [6].

$$wer[kW] = \left(\frac{BHP}{E_m}\right) \cdot 0.7457 \frac{kW}{hP} \quad \textbf{(13)}$$

$$Cost[\$] = (Power) \cdot (Operating\ Hours) \cdot \left(\frac{Cost}{kWH}\right) \quad \textbf{(14)}$$

$$\varepsilon_m = 0.8 + 0.0319 \times \ln(BHP) - 0.00182 \times [\ln(BHP)]^2 \quad \textbf{(15)}$$

For an effective cost analysis, estimate the operating hours for an entire year to obtain an electricity cost for one year. Then estimate the lifetime of the pump, how often it needs to be repaired or replaced, and the associated costs. Also, engineers need to contact the pump vendor and ask for a quote on the pump to get an initial cost. This information can be used to perform a simple life-cycle analysis. Consult Example 1 to see how to do this analysis.

Suction specific speed

The specific speed is a useful index to help get a general idea of the type of pump to be chosen. All pumps can be broadly classified with a "dimensional" number, as shown in Equation (16).

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}} \quad \textbf{(16)}$$

In Equation (16), N (rpm) is the actual pump rotating speed, Q (gal/min) is the pumping capacity, and H (ft) is the total head at the best efficiency point, corresponding to speed N and capacity Q. Suction specific speed (N_S, rpm) values — obtained by substituting $NPSH_a$ for H — of less than 8,500 rpm are typical for commercially available pumps [7]. Specific speed values between 8,500 and 12,000 rpm would likely have to be specially ordered from a pump manufacturer, and values greater than 12,000 rpm are typically not available at all [7].

As defined here, the specific speed represents the pump rotating speed (in rpm) at which a theoretical pump that is geometrically similar to the actual pump would run at its best efficiency to deliver a proportional flowrate.

Automated Excel spreadsheet

The main goal in developing the Excel spreadsheet is to find the total dynamic head to use in reading a pump curve. It can be downloaded at the following URL: http://design.che.vt.edu. The Excel file is broken up into several sheets to allow the user to tackle the sizing of their pump in a series of logical steps. Sheet 1 consists of user inputs and the main outputs of the Excel program (Figure 6). Sheet 2 provides a quick method to calculate the vapor pressure of a fluid using the Antoine equation. In Sheet 2, several variables for the Antoine equation are included for convenience, but the parameters for other fluids not included in the

spreadsheet can be readily found in the literature. Sheet 3 is included for finding the friction losses in the pumping system. Inside Sheet 3 are useful tables for summing the typical resistance coefficients for the valve, fitting, contractions and enlargements, and so on, and determining the relative roughness of the piping.

To perform the viscosity correction, input TDH, flowrate and viscosity (in centistokes) into Sheet 4. Then, input the correction factors from the viscosity correction chart into the appropriate cell in Sheet 4. This Excel spreadsheet uniquely draws the lines on the diagram automatically based in the user's input. In Sheet 5, power consumption can be found and will provide the annual utility cost of the pump under consideration, as a function of both the yearly operating hours and local electricity cost. ■

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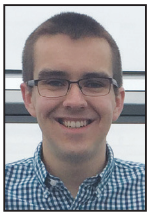

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Enclosed Combustion Equipment and Technology

A thorough understanding of enclosed combustion technologies will help engineers to select the proper equipment to balance emissions-control performance with efficiency, costs and complexity

Anu D. Vij
Ship & Shore Environmental

Selection of an enclosed combustion solution is a complex process that involves various environmental and operational requirements that are unique for each application. There is great benefit in selecting the correct equipment, since it can translate into decreased capital and operational costs by preventing over-designing or under-designing the equipment. Different technologies offer tradeoffs between initial cost, operating expense and complexity, emissions, fuel efficiency and destruction efficiency. This article describes the main categories of enclosed combustion devices and presents a few of the advantages and tradeoffs to aid in selecting the proper equipment for a particular case.

Enclosed flares

The simplest enclosed combustion device is an enclosed flare. An enclosed flare is simply meant to hide the flame and does not make a particular effort to increase combustion efficiency or reduce emissions. Enclosed flares provide cooling and combustion air through natural draft. The enclosed flare burner is simple and can be an anti-flashback type, a high-pressure type or a forced-draft type. A forced-draft type of device is used when the process gas has a tendency to produce smoke. It utilizes a blower to provide 20–40% of the stoichiometric air to the fuel gas near the burner tip. Enclosed flares typically operate at around 98% destruction efficiency.

Destruction efficiency is defined as the difference between the amount of pollutants entering the system and the amount of pollutants exiting the system divided by the mass of pollutants entering the system, expressed as a percentage. Depending on the pollutants to be destroyed, a minimum destruction efficiency is needed to meet regulations. Thus, the selection of the combustion equipment depends on the destruction efficiency needed.

FIGURE 1. These steam-generating thermal oxidizers with waste-heat boilers represent an example of an enclosed combustion technology being used for emissions control in a degassing system that ultimately generates inert gases

In order to reach higher levels of destruction efficiency, we start off with an enclosed flare design and add temperature control and assist gas. This can be called a vapor combustor, or in some cases, a thermal oxidizer. The vapor combustor can maintain higher temperatures in the chamber, which allows it to maintain a destruction efficiency of up to 99.9%. Residence time is typically around 0.7 seconds for these types of combustors.

A thermocouple is used to monitor system temperature and control the opening of the louvers or the flow of assist gas to maintain a desired chamber temperature of 1,400 to 1,800°F. Different burners can be used, including forced-draft burners for smokeless combustion of heavy hydrocarbons, anti-flashback burners and low-NOx (oxides of nitrogen) burners.

Thermal oxidizers

To reach higher levels of destruction efficiency and lower emissions, we can turn to thermal oxidizers (Figure 1). Thermal oxidizers employ a wide variety of designs, but can be generally split into three main categories: direct-fired thermal oxidizers; regenerative thermal oxidizers; and catalytic thermal oxidizers. The main difference between a thermal oxidizer system and a combustor is that a thermal oxidizer does not rely on directly igniting the process gas for oxidation. A thermal oxidizer sustains the proper conditions for oxidization of the combustible materials present in the process gas by maintaining an operating temperature sufficiently above the auto-ignition

point by providing enough time for combustion and by the presence of excess oxygen to complete the oxidation reactions (Figure 2).

Direct-fired thermal oxidizers

A direct-fired thermal oxidizer operates through the use of a burner to heat up the chamber to proper oxidation temperatures for the required destruction efficiency. The chamber must be designed to maintain an adequate residence time and provide sufficient velocity for turbulent mixing. If the process gas has sufficient heat content, it can be used as the fuel gas for the burner. Otherwise, supplemental fuel is required to maintain the combustion temperature.

A recuperative thermal oxidizer is a variation of a direct thermal oxidizer that incorporates heat recovery into the design. Heat recovery may be achieved through a heat exchanger on a hot-oil heater, a boiler or steam superheater, or may be used to preheat the process gas to increase fuel efficiency. Direct-fired thermal oxidizers offer high destruction efficiencies of up to 99.99% and can provide lower emissions of NOx and CO.

Regenerative thermal oxidizers

A regenerative thermal oxidizer (Figure 3) operates on slightly different principles. This type of system is used for applications where the combustible concentration is below 3% of the lower explosivity limit. A regenerative thermal oxidizer employs ceramic media to capture heat from oxidation to reach thermal efficiencies of up to 98%. Thermal energy is retained by the ceramic media and is then used to heat and oxidize the process gas as it enters the thermal oxidizer. To accomplish this, the system uses multiple beds and alternates the inlet and outlet of the oxidation chamber. A two-bed system would cycle approximately every two minutes, allowing heat to be captured by the ceramic media on the outlet and heating the process gas from residual heat in the inlet bed. Once the system cycles, the direction of flow is reversed, allowing the temperature to be regenerated on the beds. Through this process, a regenerative thermal oxidizer can operate on little to no fuel and achieve 98.5% destruction efficiency and low NOx and CO emissions, even with extremely lean process gases (gas that contains few or no liquefiable liquid hydrocarbons and is not able to combust on its own, usually requiring additional outside fuel to initiate combustion). The addition of a purge step to the cycle requires at least one additional bed, but increases destruction efficiency up to 99.5% by ensuring that any process gas that is present partway through a bed during a cycle transition is completely oxidized.

Catalytic thermal oxidizers

A catalytic thermal oxidizer is another type of thermal oxidizer that is used when high fuel efficiency is required. This type of oxidizer utilizes a catalytic bed to promote oxidation, lowering the temperature required to oxidize the process gas. Because of the lower temperature, a catalytic thermal oxidizer uses less fuel than a direct-fired thermal oxidizer and can even be designed to be self-sustaining through the use of a heat

FIGURE 2. Thermal oxidizers are differentiated from conventional combustors because they use excess oxygen to complete oxidation reactions at a suitably high temperature

exchanger to pre-heat the process gas. This type of system is limited by the combustible concentration of the process gas and is limited to components that will not poison the catalyst. For the correct applications, a catalytic thermal oxidizer can offer high destruction efficiency and low NOx and CO emissions.

Ultra-low-emissions models

A new class of advanced combustor called the certified ultra-low emissions burner can achieve high destruction efficiencies and extremely low NOx and CO emissions. This type of combustor has been used in environmentally sensitive areas to achieve best-available control technology (BACT) emissions levels. These devices use surface pre-mix combustion to create short-lived, low-temperature flames that are extremely efficient. This reduces flame temperature, resulting in low NOx, but also can provide destruction efficiency of up to 99.99%.

Selection guidance

When selecting a combustion system, emissions and destruction efficiency have become the primary criteria. Across the industry, there is pressure, and sometimes economic incentives as well, to reduce NOx and CO emissions, along with emissions of volatile organic compounds (VOCs). With this in mind, the first step should be to determine what local emissions guidelines apply to the specific device, and to evaluate the benefits in reducing emissions. There are several cutoff points to be aware of. A simple enclosed combustor will achieve about 98% destruction efficiency. This can be achieved by almost any diffuse flame burner without any additional effort. Up to 99.5% destruction efficiency can be achieved with a temperature-controlled combustor, a regenerative thermal oxidizer or a catalytic thermal oxidizer. Above that, a direct-fired thermal oxidizer or an ultra-low-emissions combustor is required. Although the difference between 99.5% and 99.9% destruction efficiency may seem small, half a percent improvement on destruction efficiency represents five times greater emissions for the former compared to the latter.

NOx emissions. NOx emissions have traditionally been especially hard to control. NOx is formed through various mechanisms during combustion, which, if not addressed, can create large amounts of this pollutant. A diffuse flame burner will generate the largest amount of NOx, so typically any enclosed combustor, even temperature-controlled models, will produce relatively large amounts of NOx. This includes direct-fired thermal oxidizers, which, even though they offer great destruction efficiency, do not greatly improve over simpler combustors in NOx generation. There are several low-NOx burners and designs that can improve NOx emissions for combustors and direct-fired thermal oxidizers. Other solutions are also available, such as ammonia injection, but that can prove to be quite expensive. Regenerative and catalytic thermal oxidizers can offer low-NOx emissions.

Fuel efficiency. Fuel efficiency is another important, yet frequently overlooked, consideration for selecting an enclosed combustion system. Where a fuel source, such as natural gas, is inexpensive, it is not always feasible to invest in a higher-cost system to increase fuel efficiency, but many products are still worth considering. Regenerative thermal oxidizers offer the greatest fuel efficiencies, recovering up to 98% of thermal energy. These systems are ideal for low-concentration and high-flowrate applications. Catalytic thermal oxidizers can also operate at high thermal efficiencies by incorporating heat exchangers to pre-heat the process gas before it passes through the catalyst. Finally, a recuperative thermal oxidizer can be used to pre-heat process gas to increase fuel efficiency, or it can be used to recover heat to use in another process in the plant. This can put the thermal energy gener-

FIGURE 3. Regenerative thermal oxidizers capture the heat from oxidation, which is retained by a ceramic media and is then used to heat and oxidize the process gas

ated by the thermal oxidizer to use in generating steam or other cost-saving applications.

Handling challenging components. Other product-selection decisions revolve around the type of process gas being handled. Corrosive components, such as hydrogen sulfide and halogenated compounds, demand systems capable of safely disposing of these components. Typically, once the concentration of any of these compounds reaches a certain level, the safest and most effective way of destroying them is through specially designed direct-fired thermal oxidizers. Other combustion systems are either sensitive to the presence of these chemicals, such as catalytic thermal oxidizers and regenerative thermal oxidizers, or they are not suitable for handling more dangerous chemicals, such as with enclosed flares and combustors. Direct-fired thermal oxidizers must be designed to handle these chemicals, especially in the selection of the refractory media. For hydrogen sulfide, a ceramic-fiber blanket can be used, but the oxidizer should employ a hot-shell design to prevent acid gas condensation. For this design, a wind shield is installed outside of the oxidizer shell to prevent wind or rain from cooling the surface of the chamber. This prevents the sulfur dioxide and sulfur trioxide that is produced by the combustion process from condensing into sulfurous and sulfuric acids. For halogenated compounds, a high-grade refractory media that is high in alumina and can withstand the corrosive products of combustion must be used

With all the different factors that can influence the selection of an enclosed combustion system, it can be difficult to determine where to start. In general, the decision factors should prioritize process-gas composition, followed by emissions, and finally fuel efficiency and capital costs. Following these priorities ensures that the equipment selected provides the required performance at the least capital and operational costs. Proper selection requires that these factors be researched and determined in advance to ensure that the expectations for the equipment are in line with the operational requirements. Armed with this information, the descriptions in this article can provide a starting point for equipment selection to ensure that the final decision achieves the requirements for the application. ■

Edited by Mary Page Bailey

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Operating Strategies for Gas Dehydration Units

The presence of certain contaminants can wreak havoc on gas dehydration systems and other similar separation processes, but there are design measures that can help to minimize the issues caused by these substances

Krishnan Madan Mohan and Suman Pachal
WorleyParsons Engineering Oman

The presence of the aromatic compounds benzene, toluene, ethylbenzene and *p*-xylene (BTEX) and acid gases, such as hydrogen sulfide (H_2S) and carbon dioxide (CO_2), in the wet gas of tri-ethylene glycol (TEG) gas-dehydration units (Figure 1) can result in numerous operating problems. These problems can be minimized by optimizing certain operating parameters and paying careful attention to details during the equipment design stage. This article presents several ways to minimize operating and maintenance problems in TEG gas-dehydration processes.

In TEG-based natural-gas dehydration units, most operating and maintenance problems usually occur when the circulating glycol becomes contaminated. The contaminated glycol has a tendency to cause foaming and fouling. Foaming can increase glycol loss and reduce plant capacity. Foaming can also result in poor mass transfer between the gas and the glycol solution and can affect treated-gas quality. Furthermore, contaminated glycol will aggravate fouling in heat exchangers. Fouling in the exchanger for the lean and rich glycol streams will result in poor heat transfer, which in turn will increase reboiler duty and affect the purity and quality of lean glycol, and even potentially cause pump failure. For longterm trouble-free operation of glycol units, it is important to eliminate or minimize the occurrence of foaming and fouling.

Process basics

Figure 1 depicts a typical layout of a TEG-based dehydration unit. After the removal of oil and some condensate from the wet gas stream, it is necessary to remove most of the associated water. The free water associated with the extracted natural gas is removed by simple separation methods at production stations or near the wellhead. The equilibrium water vapor that exists in the natural gas is removed by a gas dehydration process. The glycol is used as a dehydrating agent, since it has high chemical affinity toward water. Typically, a TEG unit follows these conventions.

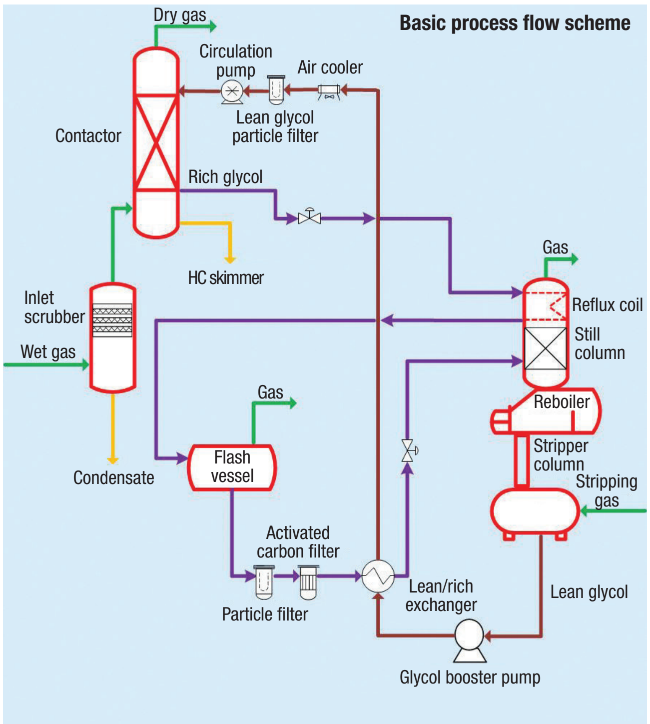


FIGURE 1. This schematic shows the layout of a typical gas-dehydration unit

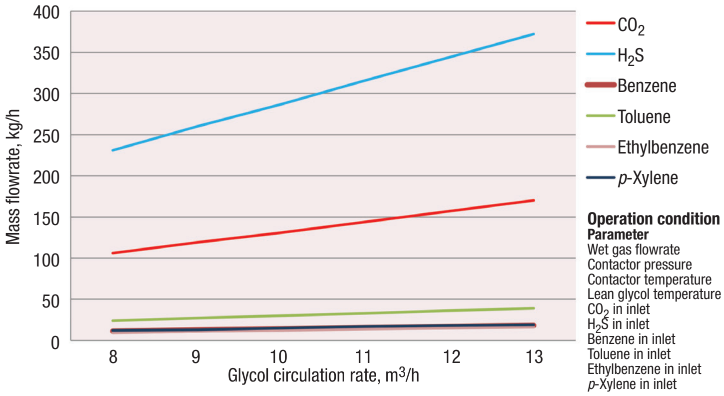
Wet gas from the wet-gas separator is sent to the bottom of the contactor in the glycol dehydration unit. Lean and water-free glycol is fed to the top of the contactor, where it countercurrently contacts the wet gas stream flowing from the bottom to the top of the contactor. The lean glycol removes water from the natural gas by physical absorption and will flow to the bottom of the contactor. Upon exiting the contactor, the glycol stream is referred to as "rich glycol." The dehydrated gas leaves from the top of the contactor through the exchanger and is routed to the hydrocarbon-gas dewpointing unit.

The rich glycol from the bottom of the contactor is routed to the TEG regeneration unit for initial heating in the glycol reflux-condenser tube bundle and passes to the glycol flash vessel, where hydrocarbon vapors will be flashed off and liquid hydrocarbons (HC) will be skimmed from the glycol. This step is necessary because the contactor is operated at high pressure, and the pressure must be reduced for adequate separation in the regeneration process. Due to the composition of the rich glycol, a vapor phase with high hydrocarbon content is formed when the pressure is lowered. The gas-free rich glycol is filtered through particulate and

activated-carbon filters to remove contaminants.

The rich glycol is then routed to the glycol still column (also known as the glycol regenerator) through the lean/rich glycol exchanger, where rich glycol is heated. The rich glycol flows downward through the glycol-regenerator stripping column for water removal.

The lean glycol from the glycol regenerator is transferred to the glycol contactor by the glycol booster and circulation pumps through the cooler and particle filter. An air cooler is deployed to cool down the lean glycol before it enters into the glycol contactor for the effective gas-dehydration process.



Operation condition and feed composition

Parameter	Value
Wet gas flowrate	10 million std. m^3/d
Contactor pressure	80 bara
Contactor temperature	40°C
Lean glycol temperature	45°C
CO_2 in inlet	7,062 kg (9.1 mol %)
H_2S in inlet	4,463 kg (7.4 mol %)
Benzene in inlet	36 kg (0.026 mol %)
Toluene in inlet	66.2 kg (0.04 mol %)
Ethylbenzene in inlet	25.4 kg (0.01 mol %)
p-Xylene in inlet	24.8 kg (0.01 mol %)

FIGURE 2. The solubility of contaminant species in glycol should be considered when specifying the glycol circulation rate for a system

Solubility of BTEX and acid gas

The amount of BTEX absorbed in the contactor is a function of several parameters, including the solubility of BTEX in the glycol used, the BTEX concentration in the feed gas, the absorption pressure and temperature and the glycol circulation rate (see Figures 2 and 3). Note that operating pressure does not have a strong effect on aromatic absorption. Commonly used glycols for dehydration applications are TEG, ethylene glycol (EG) or diethylene glycol (DEG). While TEG is the most common glycol used in gas dehydration applications, it also absorbs significantly more hydrocarbons than EG or DEG.

Glycol has a tendency to absorb acid gases. Acid-gas solubility is a major concern when TEG is used as an absorbent in gas dehydration plants. The solubility of acid gas in TEG is favored at low temperatures, high pressures, higher TEG concentration, more TEG solution circulation rate and higher partial pressure of acid gas in the feed gas (see Figures 4 and 5). If acid gas is present in significant quantities in the wet gas, then it will increase the

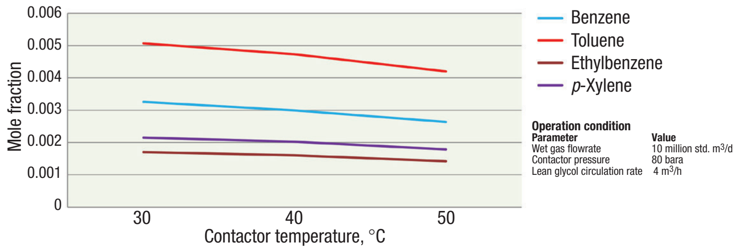


FIGURE 3. The contactor temperature is another parameter that affects BTEX concentration in the glycol

saturation water content of the natural gas. The presence of acid gases in the TEG solution lowers its pH and enhances corrosion in the glycol circuit.

In addition, another major concern is dealing with the emission of BTEX and H_2S from the still regenerator. In most countries, these components are considered hazardous air pollutants, and emissions of these components are strictly regulated.

Operating and maintenance issues

TEG units are typically capable of operating with few issues. However, there are some problem areas that can occur when the circulating glycol solution gets dirty. To ensure trouble-free operation, it is necessary to recognize these problems and know how to prevent them. Some of the major problems are as follows:

- Foaming
- Corrosion and fouling
- Glycol losses
- Thermal degradation of glycol
- Salt contamination
- Sludge formation
- Oxidation
- Low pH

Although there are several additional concerns, this article limits the discussion to the mitigation of foaming, corrosion and fouling, low pH problems and the effects of aromatics and acid gases.

Foaming

One of the most serious and common problems encountered in gas dehydration units is foaming. The root cause of foaming is often difficult to identify. However, if the circulating glycol solution is not continually cleaned by filtration, then it can cause foaming. Some of the major factors that promote foaming are entrained hydrocarbon liquids, dissolved aromatics, H_2S in the glycol, salt contamination, field corrosion inhibitors, excessive turbulence and high vapor-to-liquid contacting velocities.

Corrosion and fouling

Corrosion is another major issue in glycol dehydration units. A pure glycol solution is non-corrosive to carbon steel. However, the presence of impurities in the glycol solution causes corrosion to occur. The impurities may come from oxidation or thermal decomposition of the glycol, or they may enter into the solution from the gas stream, which is subjected to upstream purification and processing. Glycol can react with sulfur compounds

present in the feedgas stream. The resulting materials tend to polymerize during the regeneration process, and form a thick, messy substance that is very corrosive. This substance also inhibits effective heat transfer in the reboilers.

The corrosion rate depends upon various factors, including temperature and velocity. If the glycol solution is not properly cleaned, it may result in glycol oxidation or thermal decomposition in the reboiler due to higher temperature, which will lead to corrosion.

Fouling can result in leakage and poor heat transfer in plate-and-frame heat exchangers, which will increase heat flux in the reboiler system.

Low pH

The most troublesome corrosive contaminants, including products of glycol oxidation or thermal decomposition, as well as acid gases absorbed from the gas stream, can also lead to conditions of low pH. The ideal glycol pH should be in the range of 7 to 7.5. Practically, it may not be feasible to maintain this range for a long period, but it is both recommended and possible to maintain system pH above 6 continuously. If glycol circulation rates result in more acid-gas absorption, low operating temperatures may occur, which may in turn lead to accelerated corrosion and glycol decomposition.

Recommendations

There are some suitable design and operating strategies to minimize the operating and maintenance problems that result from the presence of contaminating species in the glycol. The main design and operating recommendations are detailed in the following paragraphs.

Optimize glycol circulation. The glycol circulation rate and the absorption of BTEX and acid gas in the circulating glycol are directly proportional, as seen in Figure 2. Hence, reducing the glycol circulation rate is the most effective way of decreasing the absorption of BTEX and acid gas. While reducing the circulation rate will increase the number of theoretical stages (mass transfer stage) in the contactor column's design to achieve the desired outlet water content specifications, it does help to reduce issues like foaming, fouling and high glycol losses. A lower circulation rate can also decrease BTEX emissions and reduce the reboiler duty. However, it should be ensured that when adjusting the glycol circulation rate, the system can still meet the minimum wetting rate and achieve adequate liquid distribution in the contactor, which is essential for effective mass transfer between the gas and glycol to facilitate the required water removal.

Avoid hydrocarbon carryover and condensation. The glycol is chemically reactive and needs to be protected against contamination. Major operating problems can arise due to inadequately designed glycol contactor-inlet scrubbers or separators. An inlet-gas scrubber or separator can be provided upstream of the contactor to avoid liquid hydrocarbon carryover to the contactor. The integral scrubber, as part of the contactor, should not be used as the primary separator. The primary separator must be be properly sized with suitable internals to remove liquid hydrocarbons, free water, solids and other chemical agents. Even small quantities of contaminated

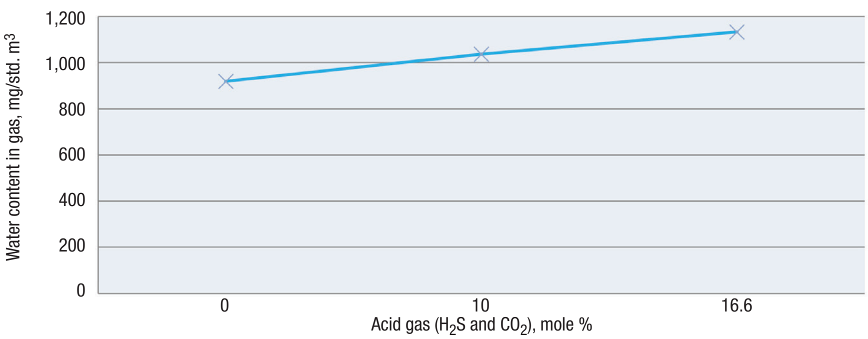


FIGURE 4. The concentration of acid gas in the glycol negatively impacts the effectiveness of the process to remove water from the gas

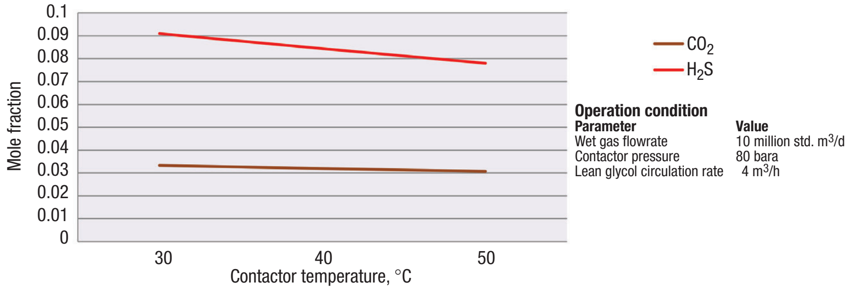


FIGURE 5. As with BTEX compounds, the contactor temperature impacts the concentration of acid gases present in the glycol

materials can result in excessive glycol losses due to foaming, reduced efficiency and additional maintenance problems. Heavy hydrocarbons in the glycol can cause coking on the reboiler surface, creating hot spots on the firebox and plugging in the regeneration system. Heavy hydrocarbon presence can also increase reboiler heat load due to elevated boiling points, and result in glycol losses.

Condensation in the contactor can be prevented by maintaining the inlet glycol temperature 3 to 6°C above the feedgas inlet temperature. If not maintained, condensation of the hydrocarbon might occur, which can cause foaming and increase glycol losses.

Flash vessel considerations. The glycol flash vessel is used to remove light hydrocarbons, acid gases and small amounts of aromatics by rapid reduction in pressure (flashing). Degassing in the flash vessel before the rich glycol enters the lean/rich exchanger helps to prevent foaming and fouling in the exchanger and reboiler. If hydrocarbons such as BTEX are present along with CO_2 and H_2S in the rich glycol, then a preheating step is more efficient for the degassing process. The recommended preheating temperature is about 70 to 75°C, and the recommended operating pressure of the flash vessel is around 3 to 5 bara.

Activated-carbon filter. A properly designed activated-carbon filter can effectively remove most foaming- and fouling-promoting compounds in the glycol. The filter should be installed downstream of the particle filters in the rich glycol line. Carbon filters are usually sized for glycol loading of 2.5 to 5.0 m^3/h per m^2 of filter cross-sectional area. If the rich glycol contains dissolved components, such as BTEX, H_2S, CO_2 or heavy hydrocarbons, it is suggested to install two full-flow activated-carbon filters in parallel with no bypass line. If the filters are not designed for full flowrates, then foaming and corrosion impurities in the rich glycol will enter into the lean/rich exchanger, regenerator system and circulation pumps. The impurities will cause exchanger fouling, leading to poor heat transfer and poor regenerator performance, which affects overall glycol purity. If the lean/rich exchanger is of the plate-and-frame type, then it will cause frequent maintenance and mechanical damage. This will also result in failure of the glycol circulation pump in the long term.

Canister- or cartridge-type synthetic-carbon filters are generally preferred when compared to loose charcoal beds (installed as fill into a vessel) because they are easier to maintain and avoid unnecessary exposure of workers to BTEX components. Contaminated spent charcoal is difficult to dispose of unless it is contained in a canister.

A synthetic-type carbon filter derived from petroleum products can be used effectively for aromatic and acid-gas removal. The main advantages of these types of filters are high surface area and high adsorption capacity compared with activated carbon derived from wood-based charcoal, coconut shell or bituminous coal.

The replacement of a synthetic-type carbon filter cannot be determined using the conventional approach of filter differential-pressure measurement, because synthetic-based carbon does not create a pressure differential after filter exhaust. The filter replacement interval should be determined based on visual examination (color comparison between inflow and outflow) or laboratory analysis of glycol samples, which can indicate high hydrocarbon content.

The ideal solution for the operational problems described in this article involves good mechanical design of the inlet separator, effective preheating of the rich glycol before entering the glycol exchanger and proper selection of a synthetic carbon filter with two filters in parallel and full-flowrate capacity with no bypass line. This will effectively eliminate most foaming and corrosion problems by removing the hydrocarbons and other troublesome impurities from the glycol, which will result in minimized operating and maintenance problems. Reducing the glycol circulation rate is the most effective way of decreasing the absorption of BTEX and acid gases in circulating glycol. ■

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Career Guidelines for Young Engineers

A senior engineer reflects on his career and shares his experience and wisdom with the next generation of engineers

Carl Rentschler
Engineering Consultant

While all engineering degrees are inherently valuable and flexible when it comes to career options, the engineering sphere has never been more challenging, and this in turn makes it difficult for many young engineers to focus their careers and make the most of the opportunities that are available. The petrochemical industry, in particular, is inherently volatile based on fluctuations in petroleum and natural gas prices, and this can lead to sudden changes in employment opportunities. This can make it difficult to maintain stable employment, and plan a reasonable, stable engineering career trajectory.

This article shares some "lessons learned" from my 40-plus-year engineering/management career (first in the nuclear industry and then in the chemical and petroleum-refining industries). My time in refining eventually encountered an abrupt downturn that led to a drastic career adjustment for me. This caused me to reflect on how I would redo my career if I could. Some thoughts shared below can provide a level of guidance to young engineers.

The situation

When I started my career as a structural engineer in the nuclear power industry, work was booming and all my boss ever asked during my first few years of employment was how much overtime I could work. During those days, countries such as Japan and South Korea, were considered developing nations, and we did a significant work for such international customers to help them build their civil and industrial infrastructure.

There also seemed to be an endless amount of work for domestic utilities and companies. This boon in work led many to become complacent about their future career trajectories, and to become lulled into thinking that this bullish state would be the norm over their entire careers.

Technological developments over the last 40+ years have been mind boggling, and there seems to be no sign such innovation will slow down in the coming years. I recall at the start of my career that slide rules were the norm for doing calculations, and people stared in awe at those who had a small pocket calculator. Now the computational capabilities at our fingertips through the various technology tools are endless. It is said that a modern smartphone has more computing power than the computers on Apollo 11 that first took a man to the moon in 1969.

This rapid pace of change has necessitated constant learning to stay current with technology tools. The need for ongoing education — and a willingness to embrace change — goes well beyond calculation tools and extends into the engineering technologies in every discipline. Constant learning is a bedrock requirement of the engineering field, and is a must going forward.

Competition in the engineering field has intensified, and it is not uncommon now for clients to request a fixed-price quote for engineering services. This was unheard of at the start of my career when nearly all engineering was was done on a time and material basis. And, we are now not only competing with other engineering firms within the U.S., but are also competing internationally. This level of competition within the engineering field will continue, and is likely to intensify.

Job hopping from company to company (and even industry to industry) has become the norm as engineers push to advance their careers, or as a result of companies downsizing. At the start of my career, engineers generally joined companies with the idea that they would retire at the same company. Now lifetime employment at one company is nearly unheard of, and engineers starting their careers have to be prepared for a path that may wind in many directions.

In the U.S., companies have even adjusted their retirement programs to so-called "portable" 401K retirement-savings plans to facilitate employment flexibility. There are a lot of good technical performers who are looking for work because they were displaced due to circumstances beyond their control. This often makes it doubly difficult for the engineer to find his or

her next position since the competition is intense for the often limited positions. Also, engineers have become more productive, thanks to advances in technology and computation tools, and therefore firms need fewer engineers to do the same work. As a consultant who now assists a major corporation in talent recruitment, I often quickly see several hundred applicants for a posted position, and this trend is likely to continue.

Ideas for the future

There is no ironclad approach to ensuring an uninterrupted engineering career, but I have developed some ideas to help assist in guiding young engineering professionals. These ideas do not supplant the need to stay current with technologies and innovations, but they offer opportunities to increase your value to future employers. Here are some thoughts that will be discussed in later sections:

1. Strive to become a technical expert in a specific facet of your engineering discipline, so that you are recognized for this knowledge.
2. Develop a diverse "toolbox" of skills.
3. Become knowledgeable in contract development and maintenance, since this has become a key component of every project.
4. Consider seeking engineering work on infrastructure enhancement projects, since these generally do not face foreign competition; at least in the U.S. (in many other countries, as well), infrastructure-related engineering work promises to be strong over the next 20–40 years.
5. Remain flexible on work location and be willing to relocate.
6. Consider starting your own business.

1. Become a technical expert. At the heart of your engineering career should be the goal of being the best you can be in your chosen field. But even among all engineering professionals there are those who distinguish themselves by becoming experts in their fields. Professionals who wish to be recognized as "best in class" devote their careers toward honing their skills in a particular area. They generally become involved in code activities and write technical papers on their area of expertise. These professionals often become very important to engineering companies because they represent a trusted source to go to, to find "final answers" on complex technical matters, and often the professional recognition they garner within their industry sector can help their company to attract business. Such experts generally survive cutbacks within their companies, and if they are displaced, are generally quickly absorbed by other companies that recognize their skills.

2. Build your "toolbox." Another way to improve your value is to involve yourself in as many different facets of work as possible, even though you may not consider some areas your "sweet spot." By having different areas of expertise, you will be able to more easily switch to a different area in the event your work area becomes soft. Broader experience also allows

you to develop the ability to understand how the different pieces fit together. This broader understanding of how different functions interact is particularly valuable for senior executives who have to oversee multiple disciplines, such as engineering, cost estimating and contracts.

During my career, I have never turned down an opportunity to work in a new and different area. Over the years I have worked as a structural engineer, piping engineer, field construction engineer, estimator, procedure writer, project manager, engineering manager, and senior business executive. This broad experience has served me well in slow times, and has also benefited me for promotions because I demonstrated breadth of knowledge and flexibility.

3. Become knowledgeable in contracts. Unfortunately the engineering world has become driven by the need to write and interpret tight contracts. In my early days, I recall the executives in our company taking pride in the fact that they agreed to design a nuclear plant on a handshake. Now this is unheard of, even for the smallest tasks. The environment is so competitive that owners and engineering companies must protect themselves from the slightest errors. Lawyers play a key role here, but engineers with contract-development knowledge are key to an organization because they understand key technical attributes in the process. Developing contracts knowledge through training and experience can make an engineer immensely valuable.

4. Consider a career in the infrastructure-enhancement area. While jobs in several manufacturing areas may fluctuate over the coming years, infrastructure-enhancement work promises to grow and stay strong. It has been well documented that in the U.S., bridges, highways, underground pipeline systems, sewer plants, mass transit systems, and other people-serving facilities have exceeded their useful life.

In the U.S., the current presidential administration has pledged a huge amount of funding to remediate our infrastructure. Most of these facilities are not merely a "replace in kind", but the plan is to utilize innovative techniques to perform the rehabilitation in order to modernize and upgrade the infrastructure element. Innovative techniques can lead to very interesting engineering work, and most importantly, will generate very solid work over a considerable number of years. The opportunities will be available in government agencies, and also engineering-and-construction firms and manufacturers of engineering equipment and materials.

5. Be flexible on work location. My 40+ years has shown that engineers who were flexible on work location nearly always had work.This can be trying for families, and the family-work balance must often be evaluated. However, there can be ways to manage work location changes so there is an upside for the entire family. In my own case, a one-year move to another U.S. location allowed my wife to do a sabbatical in her teaching profession and my daughter to gain new insights at a young age. Another three-year stint at an international power project proved very rewarding from an education and travel standpoint. While modern communication systems can enable people to work remotely, there are other functions where it is essential to be at the plant site or engineering office. Being flexible on work location can be fulfilling, and will often greatly increase your value to your employer.

6. Consider starting your own business. For bold, entrepreneurial types, there is always the option of starting your own business. Under this scenario you generally have direct control over your future. Opponents to this idea will say you do not have the security of a company; however, in today's market security is not a given anyway, and, often good performers are released due to downturns in the business or challenging overall economic conditions. Being your own business owner will also cause you to go through downturns; however, in this situation with proper planning you can generally ride through the storm. I personally formed my own one-person consulting company near the end of my career and find the work rewarding and flexible.

The key to being successful in your own endeavors is to spend the first ten or so years of your career learning the business. No one should take the route of business owner without years of learning, careful consideration of ownership options and forecast studies of the business being considered. In the end, having your own business can result in a fulfilling and secure career path.

General career guidelines

The discussion above presents specific guidelines for directing an engineering career through the ups-and-downs that are certain to be encountered in a person's working life. However, there are other general thoughts that are key to increasing your chances for continued employment through your career. These are considered threshold requirements for having a successful engineering career.

1. Always be the best performer you can be. Work hard to be the best performer in your work area. Performance appraisals provide documented and timed input on your work progress, but you should seek out input on an informal basis from your boss and interfacing groups. This provides positive reinforcement, and will raise issues that may otherwise have stayed dormant until the annual review.

2. Stay current with technology changes. Learning should never stop, and every engineer should stay abreast of changes. Technical knowledge is doubling every 10 years and the rate of change is only expected to accelerate. People of my era are often criticized (rightly or wrongly) for not staying abreast of technology changes. Looking forward, young engineers should learn from this and make sure they do not become outdated.

3. Hone your communication skills. The largest gap I have seen with engineers is that both their written and communication skills lag. There are many reasons for this, but the most prominent reason is that engineers feel these skills are important. Many feel they are exempt from good communications because they are technical people, and frankly often have no interest in communications. More than ever, the ability to communicate effectively — and articulate your technical expertise and viewpoint in an effective way — with your boss, co-workers and the public is crucial in our profession, so it is an absolute necessity to seek continuous improvement in your written and oral communication skills. Technology is becoming more complex so it is essential to communicate

effectively with disparate colleagues and project team members, who are often scattered all over the world. Understanding foreign cultures and languages can be very beneficial. I personally have recommended that young engineers join an organization called Toastmasters, which works on communication skills. This worldwide organization has a club in countless major towns and cities.

4. Manage your chosen career path. Whatever path you have chosen, it is important that you manage this path. Granted, this can be somewhat limited within your company, but even there you should have occasional discussions with your boss concerning your aspirations. Also, strive to become visible to managers who influence promotions, and take on assignments that go beyond your current work area. For a young engineer, a career looks endless, but in reality, time will go quickly. Do not regret later that you should have made a different career move early on.

5. Network, network, network. Never has it been more important to stay abreast of new technologies and the current job situation through interaction with peers. People have a tendency to network only in time of need (that is, when looking for work), but this activity should be constant. Networking not only keeps you informed regarding the job market, but also keeps you informed on technology changes, thereby making you more valuable. There are organizations with a focus on promoting networking, and also various social media outlets, such as LinkedIn, promote this activity.

Closing thoughts

Determining a path forward for a young engineer can be vexing, and filled with uncertainties and indecision. A career choice that looks good today may not be the best path forward for the long-term. The one constant in looking forward is that change will always be present. Staying current with technologies is a must in our fast-changing field. Hopefully the recommendations shared here provide some key points for young engineers to consider when focusing on their careers. As I think back to my own career, I had no plan, and this led me into some tough spots along the way. We never get the benefit of "doing it all over again," but some advice from an "eminence grise" (who did some things wrong) may be helpful. Engineering is one of the most rewarding and professionally satisfying careers that you can enter. I urge all young engineers to develop a plan early on, modify it as needed along the way, and drive to a satisfying finish line. ■

Edited by Suzanne Shelley

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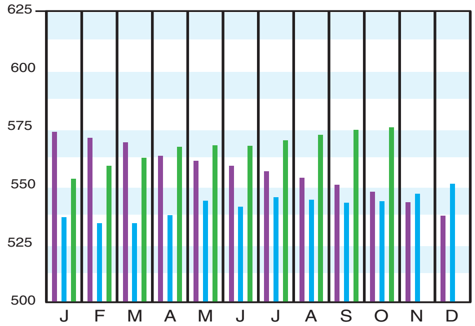
(1957-59 = 100)	Oct. '17 Prelim.	Sept. '17 Final	Oct. '16 Final
CE Index	575.1	574.0	543.1
Equipment	695.0	692.5	647.6
Heat exchangers & tanks	610.0	606.8	557.1
Process machinery	689.8	685.3	653.3
Pipe, valves & fittings	900.3	897.4	811.0
Process instruments	409.1	411.0	390.0
Pumps & compressors	985.3	985.0	966.0
Electrical equipment	521.7	521.9	511.5
Structural supports & misc.	746.7	741.8	710.4
Construction labor	331.2	334.3	329.3
Buildings	565.6	564.9	546.7
Engineering & supervision	309.6	309.8	313.7

Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

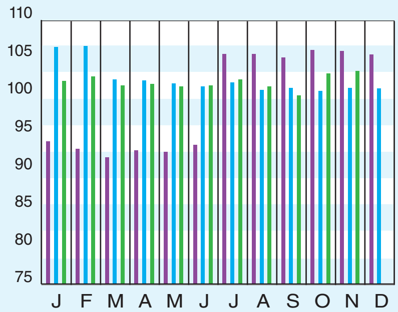
Annual Index:
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7



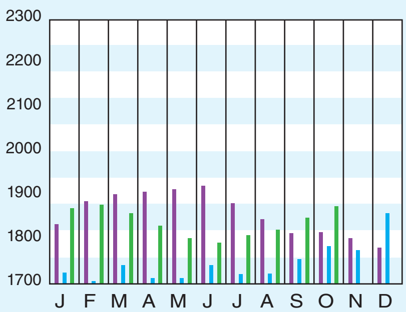
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Nov. '17 = 103.2	Oct. '17 = 102.7	Sept. '17 = 100.2	Nov. '16 = 100.5
CPI value of output, $ billions	Oct. '17 = 1,876.3	Sept. '17 = 1,856.7	Aug. '17 = 1,828.2	Oct. '16 = 1,753.1
CPI operating rate, %	Nov. '17 = 77.1	Oct. '17 = 76.9	Sept. '17 = 75.0	Nov. '16 = 75.8
Producer prices, industrial chemicals (1982 = 100)	Nov. '17 = 262.2	Oct. '17 = 262.5	Sept. '17 = 249.3	Nov. '16 = 238.9
Industrial Production in Manufacturing (2012=100)*	Nov. '17 = 104.8	Oct. '17 = 104.7	Sept. '17 = 103.2	Nov. '16 = 102.4
Hourly earnings index, chemical & allied products (1992 = 100)	Nov. '17 = 182.2	Oct. '17 = 182.5	Sept. '17 = 180.0	Nov. '16 = 169.5
Productivity index, chemicals & allied products (1992 = 100)	Nov. '17 = 102.5	Oct. '17 = 102.6	Sept. '17 = 98.2	Nov. '16 = 102.6

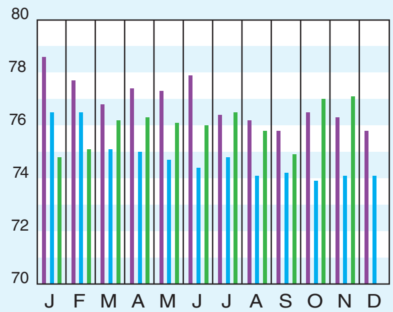
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the October *CE* Plant Cost Index (CEPCI; top; most recent available) increased compared to the previous month's value for the fifth consecutive month. Increases in October for the Equipment and Buildings subindexes offset small decreases in the Construction Labor and Engineering & Supervision subindexes. The preliminary overall monthly CEPCI value for October 2017 stands at 5.9% higher than the corresponding value from 2016. Meanwhile, the latest Current Business Indicators (CBI; middle) showed increases in the CPI output index for November, and the CPI value of output for October, along with a small decrease in producer prices for November. The CPI operating rate also inched up for November.